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MOLYBDENUM ORES

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GENERAL PREFACE

THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilization of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

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MOLYBDENUM ORES

CHAPTER I

MOLYBDENUM ORES: THEIR OCCURRENCE, CHARACTERS AND USES

INTRODUCTION

UNTIL a comparatively recent date the commercial uses of molybdenum and its compounds were very limited; in fact the greater part of the world's output was absorbed in the manufacture of chemical reagents, especially ammonium molybdate, which is used in considerable quantities for the determination of phosphorus in various technical products. Of late years, however, it has been generally recognized that molybdenum confers valuable properties on steels for special purposes, its behaviour in this respect being somewhat similar to that of tungsten and vanadium. Hence an increased demand has sprung up for molybdenum ores. Metallic molybdenum has also come into use to a considerable extent for various purposes in electrical and other work, while it is also a constituent of a number of non-ferrous alloys of remarkable properties, which are now manufactured on an extensive scale. Owing to the shortage of tungsten supplies during the early part of the war the exploitation of the world's resources of molybdenum received a great impetus, while prices rose to a very high level. It is generally understood that German munition makers in particular were then willing to pay large sums for molybdenite concentrate, and in America the consumption largely increased, the prejudice against the use of this metal formerly prevailing among American steel-

makers having been to a large extent overcome. Owing to adverse economic conditions most of the mines in the world producing molybdenum ores suspended operations in 1921; however, great advancement was made in that year in the use of the metal, and its future extensive employment seems assured.

Molybdenum Minerals

Although a large number of minerals containing molybdenum have been described, only two of them are of any practical importance, namely molybdenite and wulfenite.

Molybdenite: Molybdenum sulphide (MoS_2), the commonest ore mineral, forms hexagonal crystals, usually flat plates or short prisms with horizontal striations; it also occurs in scales, massive or finely granular. It possesses a very perfect basal cleavage, and thin flakes are flexible but not elastic. It is very soft and sectile and gives a bluish-grey streak, sometimes slightly greenish. Its lustre is metallic and its colour is lead grey, very like that of graphite but with a more bluish tinge. It is frequently confused with graphite, but differs in yielding sulphur dioxide on heating in an open tube. The specific gravity is about 4·7. When pure it contains 60% of metallic molybdenum.

Wulfenite: Lead molybdate ($PbMoO_4$) crystallizes in the tetragonal system, in square tabular or pyramidal forms, sometimes thin plates consisting of a very flat tetragonal pyramid, with fair pyramidal cleavage; it also occurs in massive granular forms. Its colour is usually some shade of greenish yellow or grey, less often orange or red, with a resinous lustre and white streak. It is easily scratched by a knife, and its density is about 7·0. Wulfenite appears to be isomorphous with stolzite and scheelite, and often contains some lime, as well as small quantities of chromium, copper and vanadium.

Among the rarer molybdenum minerals are *powellite* ($CaMoO_4$), *belonesite* ($MgMoO_4$) and *pateraite* ($CoMoO_4$), while *molybdite* appears to be a hydrated iron molybdate, produced by alteration of molybdenite in the presence of iron compounds. This mineral was formerly supposed to be molybdenum trioxide (MoO_3), but it has recently been shown that this is in-

correct, since iron is invariably present in considerable amount. *Ilsemannite* ($MoO_2.4MoO_3$) is a rare blue or black mineral formed by decomposition of other molybdenum minerals: it is soluble in water, giving a deep blue solution.

THE GENESIS OF MOLYBDENUM ORES

A general survey of the literature on molybdenum shows clearly that the vast majority of occurrences of molybdenite are either in, or closely associated with, acid plutonic rocks, especially granites. It may be found either in the mass of the granite itself, or more commonly along open joints, or as a constituent of pegmatites and other dykes cutting the granite or the country rock in its neighbourhood. It is stated that the most common metallic minerals in pegmatites are cassiterite, wolfram, molybdenite and bismuth, in the order given. Molybdenite is also found in certain veins of the deep-seated class, more or less closely allied to pegmatites, and in fissure veins of the more normal type, i.e. metalliferous lodes in the ordinary sense of the word. There is no doubt that in all these cases the mineral is of direct magmatic origin, being concentrated in the later solidifying portion of the magma, with tin, tungsten, wolfram and sulphides, according to the ordinary laws of differentiation. The common association with tourmaline, topaz, fluorspar, etc., is also of significance, and molybdenite must be classed with pneumatolytic products derived from granitic magmas.

There is also an important type of deposit in connection with crystalline limestone and various lime-silicate rocks (*skarn* of the Scandinavian geologists), resulting from thermal metamorphism and metasomatism of calcareous sediments at and near granite contacts. In these cases there has obviously been a transfer of material from the granitic magma to the sediment, as well as recrystallization. Some important Canadian occurrences belong to this type.

Wulfenite, the only other important ore, appears to be, in most cases at any rate, a secondary mineral, being found in the oxidation zone of areas where both lead and molybdenum occur as sulphides in depth. This appears to be the case in

the western United States, where it forms an important ore (see p. 65).

Concentration of Molybdenum Ores

The concentration of wulfenite ores is comparatively simple, for the mineral is heavy and is easily wetted, so the ordinary methods of water separation can be without difficulty applied, and a high recovery can be obtained. But this result is modified when other lead minerals, including vanadinite, are present. These being also heavy are generally inseparable, and lower the grade of the concentrate. Pneumatic concentration is also applicable to wulfenite ores and may be used where water is scarce.

The treatment of molybdenite ores on the other hand is more complex, for the mineral, owing to its perfect basal cleavage, is very flaky, possessing a large surface in proportion to its weight. Its surface is also peculiarly "greasy." Owing to this and to its flaky texture the mineral always tends to float, and the methods of wet gravity concentration are not applicable for its recovery. A successful method of concentration for molybdenite is a matter of the greatest importance, for its ores are generally poor, their average content being about 1% of molybdenite; over 2% is rare. Two kinds of concentration processes only have been used so far: (1) Electrostatic and (2) Flotation.

The application of electrostatic processes depends on the fact that molybdenite, like most other sulphides, is a better conductor of electricity than the usual gangue minerals, and so is amenable to separation by electrostatic means. The best results are usually obtained with rather coarse crushing, the ore being quite dry and preferably warm. One drawback to the employment of electrostatic methods is the fact that all the sulphides in an ore are recovered together, methods of separation not being commercially available. It is doubtful if any electrostatic separators are now treating molybdenite ores on a commercial scale.

As would be expected from the tendency of molybdenite to float, as referred to above, the most successful methods of

concentration are those employing water or oil flotation. In Canada and the United States the Wood process of water flotation has been successfully used with certain ores, as for example those of the Quyon mine, Quebec, but oil flotation is far more generally and successfully used. In Norway the Elmore vacuum oil-flotation process has been in use with good results for many years, but later the frothing process of oil flotation of Minerals Separation, Ltd. has been more generally used, especially in Australia.

In case an ore contains coarse molybdenite it is usually passed through rolls to flatten the mineral, which is soft and flexible, so that it may be separated from the rest of the ore by coarse screening. This preliminary separation reduces over-grinding of the valuable mineral with its increased tailing loss.

Metallurgy of Molybdenum

The metallurgical processes employed in the reduction of molybdenum in ores to the metallic state naturally vary according to whether the ore is molybdenite or wulfenite. In the treatment of molybdenite concentrate two methods are in use, as follow:

In the electric fusion process the ore is heated in a carbon tube by a current of 350 amperes at 60 volts. Sulphur dioxide is evolved and the current is afterwards increased to 900 amperes at 50 volts, when the sulphur is entirely expelled and complete fusion obtained. The metal so produced may contain as much as 7 % of carbon, which is removed by heating with molybdic oxide.

The alumino-thermic process is carried out by mixing finely divided metallic aluminium with the concentrate and igniting the mixture, when metallic molybdenum is produced in a fused state. The metal may contain as much as 1 to 2 % of iron and small quantities of silicon. This is the process mainly in use.

Two different methods have also been used for the treatment of wulfenite. In the leaching process an alkaline solution, such as sodium sulphide, is commonly employed: the molybdenum passes into solution as sodium thio-molybdate, the lead and precious metals remaining in the insoluble residue.

In 1919 this process was used by at least one company in the United States. An acid leaching solution has been tried, but is found to possess many disadvantages.

The essential feature of fusion processes for the reduction of wulfenite is that the fusion must take place with a compound or compounds that will reduce the lead to the metallic state and permit the molybdenum to pass into the slag. J. P. Bonardi, of the United States Bureau of Mines, in experiments on the reduction of this ore, obtained the best results when soda ash and caustic soda were used in combination, the ratio of ore to the combined fluxing materials being as 4 is to 3. Carbon was used as fuel. The recovery of lead and molybdenum was over 95 %. In these tests the lead was recovered as metal with any gold and silver that might be in the concentrate, and the molybdenum remained in the slag as soluble sodium molybdate. This was leached out of the slag with water, and on adding calcium chloride to the solution till neutral, and boiling, calcium molybdate was precipitated [1].

Ferro-molybdenum is commonly produced directly from molybdenite in an electric furnace. At the plant of the Dominion Molybdenite Co. at Orillia, Ontario, Canada, the process employed is as follows: A wrought-iron jacket, fitted to a cast-iron base, is connected with one terminal of the electric supply. Inside the iron jacket a cubical crucible, with a tap-hole in the bottom, is built up with carbon blocks, the space between the crucible and the jacket being filled with magnesia bricks. The second electrode consists of a 10-inch graphite rod, held by a water-cooled head over the centre of the furnace. The power used is 4,000 amperes at 50 volts.

The smelting mixture consists of 70 % molybdenite concentrate and 30 % pyrite, while coke is the reducing agent and lime and silica are used as fluxes. The ferro-molybdenum produced has approximately the following composition: Molybdenum, 71·0; carbon, 3·66; sulphur, 0·08; phosphorus, 0·03; silica, 1·35; iron, 23·8 %. About 80 % of the molybdenum in the charge is recovered in the alloy with a power consumption of 6 to 7 kilowatt-hours per lb. of alloy. The remainder of the molybdenum is recovered as dust or by wet dressing of the slag [2].

Five typical analyses of ferro-molybdenum, as now made by the electric furnace process, gave the following ranges of percentage composition: Molybdenum, 75·00 to 85·80; iron, 10·96 to 49·30; carbon, 0·35 to 4·00; silicon, 0·11 to 0·30; sulphur, 0·02 to 0·05; phosphorus, 0·01 to 0·03 [3] [4].

The phosphorus in the above analyses appears to be somewhat low; the usual range may be taken to be from 0·02 to 0·06 %.

Properties of Molybdenum

Pure molybdenum is a silvery-white metal, with a density of 10·0, and is comparatively soft, malleable and ductile; it is only since 1906 that it has been found possible to draw it into wire. Its melting-point, though still somewhat uncertain, is undoubtedly very high, probably about 2,500° C. Its tensile strength, when it is drawn into wire, is about half that of tungsten or steel wire of the same diameter. Metallic molybdenum as obtained by metallurgical reduction is impure, owing to absorption of carbon, and possesses properties somewhat different from those of the pure metal obtained by a special method (e.g. by submitting pure molybdic trioxide (MoO_3) to a current of hydrogen at a red heat); it is grey and brittle and hard enough to scratch steel, and its density is slightly below 9·0. At ordinary temperatures it oxidizes very slowly, but at 600° C it combines with oxygen to form the trioxide. This oxide is acid-forming and gives rise to the molybdates, the best-known compounds of the metal. The sodium, potassium and ammonium salts of molybdic acid are soluble, while the salts of most other bases are insoluble, some of them occurring as natural minerals as before described. Ammonium molybdate possesses the important property of forming an insoluble yellow compound with phosphoric acid, a fact which is of much importance in analytical chemistry in the determination of phosphorus in a large number of technical products: several tons of ammonium molybdate are used each year in the laboratories dealing with iron and steel and fertilizers.

Uses of Molybdenum

As already stated in the introduction, the principal use of molybdenum at the present time is as a constituent of special

varieties of steel, to which it imparts properties valuable for particular purposes. About thirty years ago the use of molybdenum in steel was almost universally condemned. The poor results of the earlier investigators were largely due to the impurity of the molybdenum or ferro-molybdenum used, and also to improper heat treatment.

In 1904 the use of molybdenum in high-speed tool steel was investigated by J. M. Gledhill, who found that where a large percentage of tungsten is necessary to make a good high-speed steel, a considerably less percentage of molybdenum will suffice, and also that the presence of from 0·5 to 3 % molybdenum in a high tungsten steel slightly increases the cutting efficiency [5].

A few years later Thomas Swinden thoroughly investigated a series of carbon-molybdenum steels ranging in composition up to 8 % molybdenum and 1·2 % carbon. He proved the extreme susceptibility of these steels to heat treatment, and, among other things, demonstrated that hardened and tempered steels, containing from 1 to 2 % molybdenum, possess extremely high tenacity values, accompanied by high ductility; but with higher percentages of molybdenum the steels become inferior. The results obtained by Swinden are embodied in two memoirs [6] [7].

Molybdenum tool steels were manufactured for some years, but in 1915 the use of molybdenum in such steels was being discontinued, on account of irregularity in quality, various imperfections, such as seams and flaws, and wide differences of behaviour under similar treatment [8].

In 1919 Arnold and Ibbotson experimented with molybdenum-vanadium and tungsten-vanadium high-speed tool steel, and showed that steels of the former alloy had a greater cutting efficiency than those of the latter. They used steel with upwards of 5 % molybdenum in some of their tests [9]. Such a percentage is now considered too high for a high-speed tool steel, especially by American metallurgists, who think, indeed, that commercially successful molybdenum high-speed steel has not yet been produced [10].

In recent years it has been found that a content from a small fraction up to 1 % molybdenum has a beneficial effect on the

physical properties of mild structural steel. It may be added alone to carbon steel, or to a steel already containing chromium and nickel, or chromium and vanadium. Molybdenum steels, when compared with other alloy steels and heat-treated to the same tensile strength, show (1) a slightly higher elastic limit, hence a somewhat higher elastic ratio; (2) a higher elongation, hence greater ductility; and (3) a much higher reduction of area, hence appreciably greater toughness [10]. Moreover, the use of chromium-molybdenum steels effects a greater saving than that of other alloys fabricated into finished parts that have been forged or machined. In rolling, as in forging, the oxide scale parts very easily from the steel, and in heat treatment the steel may be subjected to a very wide range of temperature without impairing the physical properties [11/1920]. Carbon-molybdenum steel, because of its great ductility, is especially suitable for machine parts which require extremely difficult forming operations, and the steel can be treated to possess high strength, e.g. for shovels and for motor car frames. A chromium-molybdenum steel of a single type in two or three carbon grades develops under suitable heat-treatment a sufficient variety in physical properties to meet all the demands of motor car construction [10].

The following table gives ranges of composition of molybdenum steels that have actually been used in the motor car, aeroplane and other industries:

	1.	2.	3.
	%	%	%
Carbon	0·15–0·40	0·40–0·50	0·25–0·35
Manganese	0·40–0·80	0·60–0·90	0·50–0·80
Silicon	0·70–1·10	0·10–0·20	0·10–0·25
Chromium	0·10–0·20	0·80–1·10	0·70–1·00
Nickel	—	—	2·75–3·25
Molybdenum	0·25–0·40	0·25–0·40	0·30–0·50
Tensile strength, lb. per sq. in.	145,000–170,000	200,000–230,000	150,000–265,000

1. Used for motor truck and tractor, propeller shafts, etc.
2. Used for springs in motor car industry.
3. Used for aeroplane crank shaft, Liberty motor crank shafts and rods, etc. [12/1920, p. 48].

Besides motor car frames, carbon-molybdenum steel is used for axle-housings, tire-rims, disc or wire wheels and other

parts where the lightest weight consistent with strength is economical.

Molybdenum steels are also used for high-pressure boiler plate, linings for big guns, rifle barrels, armour plate and armour-piercing projectiles, and it is reported to be of advantage for steel balls for grinding mills [13]. The function of molybdenum in the complex alloy steels is to prevent segregation and crystallization, to promote uniformity of texture and to secure a degree of toughness in steel that is always more or less lacking in the alloys of more common use [14].

Molybdenum steel is generally made by the crucible process, occasionally by the open-hearth process or in the electric furnace. The molybdenum may be added (as the charge is melting down) in the form of the powdered metal, as ferro-molybdenum, an alloy with iron containing anything up to 80 %, or in the form of calcium molybdate [15].

The molybdenum steels used for permanent magnets are similar in composition to high-speed steels. They generally contain 2 or 3 % molybdenum, 0·5 to 0·7 % carbon and sometimes a little chromium. They retain their magnetism better than pure carbon steels, and are said to be superior to tungsten steels for this purpose. Another special use of the metal is in the making of acid-resisting steels. It is said that an alloy with 2 to 5 % molybdenum and 10 % chromium is practically unattacked by any acids. An alloy of 60 % chromium, 35 % iron and 2 to 3 % molybdenum is said to be unaffected by boiling aqua regia. Furthermore, molybdenum is a constituent of some varieties of the group of alloys known as stellite, which contain little or no iron. The following is a typical analysis of a molybdenum stellite: Cobalt, 59·50; chromium, 10·77; molybdenum, 22·50; manganese, 2·04; iron, 3·11; carbon, 0·87; silicon, 0·77; sulphur, 0·084; phosphorus, 0·040 %. The alloys of this group possess many of the properties of high-speed steels.

In the electrical industry metallic molybdenum is used as wire for supporting the filaments in incandescent electric lamps; for the windings of electric resistance furnaces; as a substitute for platinum and for platinum-iridium in various contact-making and contact-breaking devices; and in the

manufacture of some types of X-ray tubes. It is also used in dentistry [16].

Molybdenite is used as a rectifier in wireless telegraphy. Various compounds of the metal are employed as chemical reagents, as pigments for silks, woollens, earthenware, leather and rubber, and for producing a yellow glaze on porcelain. It is also stated that a compound of molybdenum is used as a preservative for smokeless powder in hot climates.

Prices of Concentrate and Metal

For a good many years before the war the price of molybdenum metal was fairly constant, at an average of about 6*s.* per lb., but in 1918 ferro-molybdenum with 50 to 60 % molybdenum was selling at about 16*s.* per lb. of molybdenum metal content. At the end of 1920 the same grade was quoted in New York at $2 per lb. of contained metal, f.o.b. works.

During the war the price of molybdenite concentrate was strictly controlled by the British Government acting in agreement with the governments of the Dominions, the price being fixed at 105*s.* per unit of molybdenite (MoS_2) (1 % of a long ton) delivered f.o.b. Liverpool. In Canada the corresponding quotation was $1·09 per lb. of molybdenite, f.o.b. Ottawa. On the other hand the uncontrolled price in the United States was on the average about $2·25 per lb. of molybdenite. As exportation of British molybdenite ores to countries outside the Empire was forbidden, this worked somewhat hardly on Canadian producers. Owing to cessation of demand for munition purposes and to over-production the price fell in February 1919 to 85 cents per lb. of molybdenite in 85 % concentrate, and at the end of 1920 it stood at 55 to 60 cents per lb., the corresponding English price being about 65*s.* per unit, c.i.f. United Kingdom.

The World's Production of Molybdenum

Till recently it has been difficult to obtain reliable figures as to the world's output of molybdenum, owing to a variety of causes. In the first place the quantities produced by some countries are very small and in some returns they are not listed

separately. Again, ambiguities arise from the want of a definite standard, such expressions as "molybdenite concentrates" without a statement of metal or sulphide content being of little value, since the molybdenite (MoS_2) content in commercial ores varies between very wide limits.

Estimates of the metallic contents of the molybdenum concentrates produced by various countries are given in the following table:

World's Production of Molybdenum[6]

(Metal contents of concentrates in metric tons)

	1915.	1916.	1917.	1918.	1919.	1920.	1921.
Australia[1,2]	70·8	74·2	94·4	105·1	95·5	35·5	5
Bolivia	6·5	5·2	—	—	—	—	—
Canada[1]	8·0	42·5	89·9	102·9	30·9	nil	nil
Chile	—	0·8	20·1	—	—	—	—
China	—	2·7	2·4	1·1	—	—	—
Korea	—	3·2	59·2	10·7	—	—	—
Japan	—	18·3	12·1	70·3[3]	—	—	—
Mexico[4]	—	—	—	14	1	0·3	2
Norway	72·3	73·1	82·1	84·9	—	—	—
Peru	1·3	3·1	3·8	1·3	2·5	1·0	—
Spain[1]	5·2	26·7	—	—	—	—	—
Sweden	—	0·3	20·3	25·1	—	—	—
United States[5]	82·4	93·8	158·8	390·8	135·2	15·8	nil

Some trifling productions were made in Italy, India and Austria (now Yugo-Slavia), *see* p. 62. The productions of Germany are not available.

[1] "Prod. of Copper, Gold, Lead, etc. in Canada in 1918," *Can. Dept. Mines, Mines Branch*, 1919.

[2] *Mines Repts.* of various Australian states.

[3] Ore ("54·7 tons coarse ore of low grade").

[4] *Mineral Industry* and *Eng. and Min. Jour.*

[5] "Cobalt, Molybdenum, etc. in 1920," *Min. Res. of U.S., U.S. Geol. Survey*, 1922, p. 403.

[6] "Min. Res. of the United States in 1920" (Prel. Summ.), *U.S. Geol. Survey*, 1921.

CHAPTER II

SOURCES OF SUPPLY OF MOLYBDENUM ORES

(a) BRITISH EMPIRE

EUROPE

ENGLAND

MOLYBDENITE has been recorded from a considerable number of localities in England, but only in small quantity. It is found in many places in the mining districts of West Cornwall in association with ores of tin, copper, tungsten and arsenic. According to the publications of the Geological Survey it has been noted at Wheal Mary, Lelant; Wheal Friendship, Marazion; Wheal Gorland and Wheal Unity, St. Day; Gwinear; Menabilly, near Fowey; Cligga Head; and Drakewalls mine, near Calstock [17]. From a remark in the description of the Drakewalls mine in the memoir just quoted it would appear that at one time it was worked there in commercial quantities, but no details are given. None of the other occurrences appears to be of any commercial importance. Molybdenite has recently been found in a lode with tin and wolfram, and in the country rock at Killifreth mine, between St. Day and Chacewater Station. It has also been seen in old dumps at Kit Hill, Callington.

Molybdenite has also been noticed along joint-faces in the granite of Mount Sorrel, Leicestershire [18], though only in small amount, and in the Shap granite it is occasionally found in geodes and as a deposit along joint-faces in association with pyrite, chalcopyrite, arsenopyrite, malachite, fluorspar and calcite [19].

At Carrock Fell, Cumberland, 7 miles from Troutbeck Station, molybdenite is abundant in a single vein, almost free

from tungsten; it is present also in smaller quantities in the normal wolfram-scheelite veins with arsenic, bismuth and a trace of gold [20]. The scheelite of this locality is shown by analysis to contain a considerable quantity of molybdenum replacing tungsten.

Scotland

At the Breadalbane mines, Tomnadshan, near Killin, Perthshire, molybdenite is found in small quantity in acid veins cutting a boss of basic igneous rock intrusive into epidiorite and mica-schist; it is associated with chalcopyrite and tetrahedrite [21].

Molybdenite has also been found in unimportant quantities at several other localities in Scotland, as for example in the granites of Galloway and Ben Cruachan; in granites near Bonawe and Creran in Argyllshire, and at Dochfour Burn, Inverness [22].

Ireland

Molybdenite has been recorded in two or three localities in Ireland, but little is known about the occurrences. Kinahan has described molybdenite as being present "in quantity" in what appears to be a dyke cutting granite at Murvey, a few miles west of Roundstone, Co. Galway [23]. Some prospecting and boring operations were carried out in 1915, but work was stopped owing to difficulties as to the title of the lands in question [11/1919, p. 472]. The same mineral has also been found in coarse granite on the N.W. side of Lough Anure, Co. Donegal, and again at Lough Laragh, in the same county, in a small acid dyke penetrating a pyroxenic rock, while a metamorphosed limestone band in the same neighbourhood also shows traces. Molybdenite has also been recorded in the island of Inishdooey, off the Foreland of Donegal.[1]

From a consideration of the above facts it may be concluded that at present there is no prospect of any production from the British Isles, although minute quantities will doubtless be discovered in other localities as mining development progresses, especially in Cornwall.

[1] Personal communication from Prof. G. A. J. Cole and Mr. T. Hallissy.

ASIA

Ceylon

Molybdenite, associated with some pyrite, occurs in a vein of pegmatite from 5 to 6 ft. in thickness, at Hetimulla, 4 miles from Kegalla, Ceylon, and the mineral has also been found disseminated through many rocks in Saffragam [24] [25].

India

Molybdenite in considerable quantity is associated with wolfram and tin in many parts of Burma. The mineralization of this area is due to the intrusion of Mesozoic granites into a series of more or less metamorphosed sediments of indeterminate age, probably Palæozoic or older. Numerous occurrences of molybdenite in wolfram-tin lodes have been discovered during the great development of wolfram mining that has taken place since the beginning of the war. In the Yamethin district molybdenite is constantly present in the lodes situated close to the summit of Byingyi, a peak 6,254 ft. in altitude, on the borders of Yamethin and Loi Long, Southern Shan States. The lodes all lie in granite, with a general N.W.–S.E. strike parallel to the general structure of the country: they are only about 15 in. thick, carrying wolfram, molybdenite and beryl, without tin. Molybdenite appears to be most abundant in the highest lodes.

In the Thaton district molybdenite is found in four N.W.–S.E. lodes in granite, consisting of quartz, felspar, mica and tourmaline, with wolfram, pyrite, chalcopyrite and arsenopyrite. They are thus obviously true pegmatites. Although only a few inches thick, they can be traced for 2½ miles.

In the Tavoy district in Lower Burma molybdenite is very widely distributed, and at least one property has produced it on a commercial scale. It occurs with wolfram and cassiterite in lodes in, or close to, the large granite intrusions forming the hill ranges of this large district, which covers an area of about 5,000 sq. miles. It is found:

(*a*) as an accessory mineral in the granite.

(*b*) as a constituent of pegmatite dykes, where it occurs with wolfram, cassiterite, scheelite (rarely), pyrite and other sulphides, felspar and mica.

(*c*) in quartz veins with wolfram and cassiterite, and also sulphides.

(*d*) in greisens (rarely).

(*e*) in quartz veins without wolfram or cassiterite but with pyrite.

Only one example of the last case (*e*) is known. This is at the Sonsin mine on the edge of the Tettaung granite intrusion. Very few attempts have been made to extract molybdenite in Tavoy, and the small parcels which have been shipped are in the nature of experimental trials.

The largest tungsten mine of Tavoy, and perhaps of the world, is Hermyingyi. In the ores from this mine molybdenite is found, while in the adjoining concession of Hermyingale is a thin lode containing molybdenite, pyrite, mica and cassiterite with relatively small amounts of wolfram. This is bordered by a bank of rock consisting entirely of topaz and fluorspar, with an outer layer of greisen containing pink cassiterite: the country rock is mudstone. In the Wagon area in the Thingandon concession is a large lode with walls of greisen, carrying molybdenite and wolfram with some fluorspar. Molybdenite also occurs in very considerable quantities in some of the lodes of the Wagon North mine of the Burma-Malaya Mining Co., Ltd., in the Kyaukmedaung Range. In the Shamataung section of the Widnes mine (High-Speed Steel Alloys Mining Co., Ltd.) is a lode 6 or 8 ft. wide containing wolfram, pyrite and relatively large quantities of molybdenite.

In the Palauk Concessions of the Mergui district molybdenite occurs in small quantities in wolfram-bearing lodes up to 1 ft. thick lying partly in granites and partly in sediments [26].

According to Morrow Campbell [27] the molybdenite of Tavoy is of little economic importance, as its occurrence is erratic; it is most common in veins in granite, especially at or below the bottom of the wolfram zone; in the latter case it is often mixed with mica on the walls of the vein. It appears to have been in most cases the first mineral to form, being succeeded in turn by wolfram, cassiterite, bismuth minerals, chalcopyrite, arsenopyrite, pyrrhotite, and, lastly, galena and blende.

No attempts have been made as yet to concentrate molybdenite-bearing quartz by up-to-date methods in Tavoy, and

its flaky nature prevents its successful recovery by the usual cobbing and panning practice.

The following are recent productions of molybdenite from Tavoy:

	1916.	1917.	1918.	1919.	1920.
Cwt.	8	27	4	4½	1
Value, £	202	626	62	101	19

Molybdenite is known to occur in the crystalline rocks and associated quartz veins in certain parts of Chota Nagpur, in an elæolite-sodalite-cancrinite-pegmatite at Mandaoria, near Kishangarh in Rajputana, and disseminated through the complex sulphide ores, which consist of pyrrhotite, pyrite and chalcopyrite, with small quantities of nickel and cobalt, of the Tovala taluk in South Travancore. Another occurrence of more scientific than commercial interest is in the hard granite of Retiambadi Mitta, near the village of Karadikuttam, Madura district.

Besides the localities already mentioned, molybdenite has been found at the following places in Madras: Trichinopoly [28], Kunnavaram (scattered scales in pegmatites) and Mangamalai (disseminated through a pegmatite). The mineral also occurs in a pegmatite which was cut through at a depth of 2,500 ft. in the Balaghat lode, Ooregum, Kolar Gold-field, Mysore [29] [30], and has been observed in small quantities in the Patra River, near Mahabagh; and in the Baraganda copper mine at Urmi, near Dumria, Bengal [24].

AFRICA

Nigeria

Molybdenite has been observed in association with tinstone, topaz and other minerals at one or two localities in Nigeria, especially near Jos, and in the Jarawa Hills. Around Dogon Daji, on the western margin of the Jarawa-Fusa granite, some of the numerous quartz-cassiterite veins carry molybdenite, but apparently only in small quantity [31].

Southern Rhodesia

In Southern Rhodesia molybdenite occurs in different places (notably Umtali, Bindura in the Hartley district, and near Bulawayo) in pegmatite in older granite with scheelite, wolfram and cassiterite (all three of which minerals are mined), bismuth ores, tantalite, microlite and magnetite [32].

South-West Africa.

Fine specimens of molybdenite from a pegmatite vein to the south of Usakos, South-West Africa, and also from a deposit said to exist in the Kuiseb Valley, near Walfish Bay have been seen by P. A. Wagner. Range mentions the occurrence of molybdenite in granite at Aus and also in the Velloor Hills in the Warmbad district [33].

At Gansberg, near Hornkranz, molybdenite is found in a pegmatite associated with tourmaline and limonite, and at Ubib in a reddish granite, and in schist, both disseminated and massive. Wulfenite, associated with copper oxide, has been reported from Tsumeb [34].

Union of South Africa

Molybdenite has been recorded from a considerable number of localities in different parts of the Union of South Africa, but so far as can be ascertained there has not yet been any production. In most of these cases the mineral merely appears as a local accessory in granite rocks; one occurrence, in Natal, unique in character so far as is known, is referred to below.

Molybdenite has been observed in granitic rocks at Helderberg, near Stellenbosch, Cape Province, in quartz veins associated with arsenopyrite, pyrite and chalcopyrite [35]; also at various localities in the copper district of Little Namaqualand, especially at Kamiesberg, Tweefontein, Narrap, Nababeep and New Prospect.

In the Transvaal molybdenite has been found at Appingadam and Stavoren (Waterberg district) and at Enkeldoorn and Houtenbek (Pretoria district). At Stavoren it occurs with cassiterite in a red granite: 3½ tons of 15 % ore were sorted from a dump and shipped to Europe in 1915 [36/1915, p. 501].

The Appingadam (Waterberg) deposit has been described by J. P. Johnson [37] [38]. It occupies an irregularly shaped area. The surrounding country rock is granite plentifully scattered with spherules of tourmaline. In certain centres of intense alteration peculiar types of rock have been produced which bear no resemblance to the original, and which pass one into the other. They comprise tourmaline-quartz rock, sericite-quartz rock, sericite-molybdenite rock, molybdenite-arsenopyrite-quartz rock, and arsenopyrite-fluorspar rock. Blende also occurs in irregular masses. Molybdenite in the form of scales, often hexagonal, is the dominant metallic mineral. Some molybdite also is found.

According to H. Merensky, molybdenite is an accessory mineral of the Bushveld Granite Complex. At the farm Houtenbek, near Pretoria, there are two interesting occurrences in granite. One is a band, 2 ft. in width, consisting of almost pure arsenopyrite, some fluorspar and large leaves of molybdenite. The other is a similar band showing arsenopyrite, fluorspar, and large crystals of monazite, all closely intergrown. Some of the ore was reported to have an average yield of 5 % of thorium [39]. Wulfenite has been found in small quantities in the Transvaal silver mines, Leydsdorp district [24/p. 184].

The remarkable occurrence in Impendhle Co. in Natal has been described by du Toit [40] and by F. H. Hatch [41]. It lies in the valley of the Hlatimba, a tributary of the Umkomaas River at the foot of the Drakensberg, and consists of a dissemination of molybdenite in a coarse sandstone belonging to the Molteno division of the Karroo system; the bed is about 18 ft. thick, but molybdenum is confined to the lower portion for about 5 ft. in thickness, and extends along the outcrop for about 20 yards. The sandstone is black with white spots and carries a good deal of marcasite, often in concretions. It contains about 1·85 % molybdenite; some molybdic ochre is present as well as the rare blue soluble mineral ilsemannite, an oxidation product of molybdenite or wulfenite. This ore-body appears to be irregular and of small size.

Molybdenite is also found here and there in Natal, in scattered flakes in old crystalline rocks, as at Umkukuse, 4 miles S.E. of Eshowe; in a pegmatite at Subeni; in a quartz vein tra-

versing pegmatite near the Dumisa gold mine, and in a pegmatite in syenite near the Umgeni Stream in the Buffalo Valley: none of these appear to have been explored [41].

NORTH AMERICA

Canada

Molybdenite was first discovered in Canada at Terrace Cove, Thunder Bay district, Ontario. Specimens were sent to the London Exhibition of 1851, and the deposit was described by W. E. Logan as a vein, 8 in. in thickness, striking N. 15° E., and traceable for 1½ miles, consisting of quartz with chalcopyrite and molybdenite in red felspathic gneiss [42] [43].

Since then extensive deposits of molybdenite have been found in various parts of the Dominion. The first actual shipments took place in the year 1902, when 3 tons of ore were mined; in 1903 the amount rose to 600 tons, but from 1904 to 1913 inclusive no production is recorded. Meanwhile the resources of the Dominion were being investigated by the Geological Survey of Canada, and in 1911 a report by T. L. Walker was published containing an account of all the occurrences then known [44]. In 1914 a small output was made, and during the early years of the war the industry received a considerable impetus owing to the demand for molybdenum as a substitute for, or an addition to, tungsten for special steels. In 1915 the Mines Branch of the Canada Department of Mines was able to offer its services to the Imperial Munitions Board to obtain supplies of this mineral should they be required by the Imperial authorities, and in 1916 the purchase of supplies of molybdenite in Canada by the Government for munition purposes commenced. Owing to the want of proper facilities for the dressing of molybdenum ores in the country, this subject was taken in hand by the Mines Branch, whose ore-dressing and metallurgical laboratories were turned into a commercial mill on a small scale. During 1916 this establishment turned out about 40 tons of molybdenite concentrate from 2,300 tons of ore, and in 1917 about 31 tons of molybdenite from 1,600 tons of ore. Early in 1917 two of the principal mines in Canada, the Dominion Molybdenite Co.'s mine at Quyon, Quebec, and

the Renfrew Molybdenum mines, at Mt. St. Patrick, Ontario, began to concentrate in their own mills [45/p. 105].

During the first three years of the war molybdenum in any form was under an embargo in Canada, and its export to any country outside the British Empire was prohibited; all local production was purchased by the munition authorities at a fixed price of \$1·09 per lb. of pure molybdenite, f.o.b. Ottawa, as mentioned above (p. 11). During the first week of January 1918, the embargo was partially removed, export to the United States and France being permitted. The price in the United States kept up to about the same level during 1918, but in February 1919, owing to over-production and cessation of demand for munitions, the price fell suddenly to 85 cents per lb., and most of the mines closed down.

The following table shows the total molybdenite recovered in Canada and its value for recent years:

	lb.	\$		lb.	\$
1914 . .	3,814	2,063	1918 . .	378,029	434,733
1915 . .	29,210	28,450	1919 . .	83,002	69,203
1916 . .	156,461	156,461	1920 . .	nil	—
1917 . .	288,705	288,707	1921 . .	nil	—

[46]

The molybdenite deposits of Canada are mostly found in regions of Archæan rocks in connexion with intrusions of granite. Three important types of occurrence may be recognized: Quartz veins, pegmatite dykes and granite-limestone contacts. Besides these there are found here and there segregations of molybdenite of primary magmatic origin in granite and other igneous rocks. This last group is not of very widespread occurrence, although one of the most important producing mines belongs to it. Most of the Canadian ores consist of rather low-grade material, with less than 2% molybdenite, but there are occasionally small consignments of high-grade hand-picked material, running up to 15% or even more [47].

The greater part of the Canadian production comes from

the provinces of Quebec and Ontario, with smaller quantities from British Columbia, Manitoba, New Brunswick and Nova Scotia.

British Columbia

Molybdenite has been reported at different times from a large number of localities in British Columbia. The first shipment of two car-loads[1] took place in 1914 and 1915 from the Molly mine on Lost Creek, in the Kootenay district, described below. During the war a certain amount of further development took place, and ore was shipped in commercial quantities from Alice Arm and from the Index mine, Lillooet. The Final Report of the Canadian Munition Resources Commission gives a long list of recorded occurrences from all parts of the province, but most of these are merely small prospects of wholly unascertained value, often in very remote and inaccessible districts. The following notes, compiled from various sources [44] [45] contain brief particulars of the producing mines and of some of the more promising prospects.

On Texada Island, Nanaimo Mining Division, the ore-bodies occur at the contact of granite and limestone, molybdenite in a finely granular form being associated with chalcopyrite and bornite, carrying gold and silver. Several mines were working here a few years ago, mainly for copper; these included the Marble Bay, Cornell, Copper Queen and Little Billy. At the Marble Bay mine molybdenite is found in the same shoots as good copper ore in marble, generally in thin layers along joints and slip-planes; the workings are now over 1,000 ft. deep. A sample of hand-picked ore yielded 8·88 % molybdenum and 1·85 % copper with a little gold and silver. In the other mines the molybdenite occurs chiefly in garnetiferous bands in lime-silicate rocks. The fine grain of the ore has hitherto rendered concentration difficult, but this could easily be got over by froth flotation.

In the claims known as the Allies Group, Nanaimo Mining Division, there are quartz veins, from a few inches to 5 ft. in thickness, carrying molybdenite in flakes and sometimes in

[1] A Canadian car-load is about 30 tons.

lumps from the size of coffee beans to as large as a man's fist. The ore is associated with a little chalcopyrite. A sample taken from the outcrop by W. M. Brewer [48/1918, p. 269] assayed 0·3 %; one from a vein 12 in. wide, 0·96 %; and a third from a vein 18 in. wide, 0·96 % molybdenite.

In Vancouver Island several finds have been reported, but no information of value is obtainable.

Molybdenite has been reported from several localities along the channel between Vancouver Island and the mainland, from Knight Inlet, Cortes Island, Jervis Inlet, Lyon Creek, and near the head of the North Arm, Burrard Inlet. None of these occurrences seem to be of any importance.

The copper claims of the Tamarack group, Gnawed Mt., Ashcroft Mining Division, carry chiefly chalcopyrite with some malachite and molybdenite along parallel joint-planes in grey granite: the last-named mineral makes a good surface show, but is thin; in some places it occurs as the cementing material of a black brecciated fault rock. A sample of this yielded 2·55 % molybdenum and 0·3 % copper.

Molybdenite has been observed in several mines and prospects near Rossland in the Trail Creek Mining Division. In the Grant mine it is associated with pyrrhotite, arsenopyrite and smaltite, and gold to the value of several dollars per ton is chiefly contained in the molybdenite, which is almost amorphous in character; it forms disseminations along more or less vertical joints in a metamorphosed impure limestone traversed by dykes of camptonite. A sample assayed 11·6 % molybdenum, and 3·39 oz. gold per ton. The Novelty and Deer Park claims show occurrences very similar to those of the Giant, but in smaller amount, as also do the Centre Star and War Eagle mines.

In the bed of the River Kootenay, near the bridge of the Canadian Pacific Railway, pegmatitic quartz-veins in grey hornblende-biotite-granite carry scaly molybdenite, but only the thinner ones are at all rich.

Molybdenite is said to be fairly common at Independence Camp and on Champion Creek in the Similkameen Division. At the latter it is found at a contact of gneissose granite and limestone, with pyrite, blende, garnet and epidote.

3

Twenty miles west of Marysville in the Fort Steel Mining Division is a promising occurrence of quartz veins in a quartzite, with fine-grained molybdenite. The best claims appear to be Sunnyside I and II and Sunset.

A deposit on the Stump Creek, seven miles north of the north end of Stave Lake, has attracted attention during recent years, but no ore has been shipped. This deposit is of the pegmatite type, with flake molybdenite along seams and in quartz veinlets.

The following are the most important occurrences of molybdenum ores in British Columbia so far developed: most of these have been producers within recent years [45/p. 123].

The mine worked by the Molybdenum Mining and Reduction Co., Ltd., on the north side of Alice Arm Lake, Nass River Mining Division, lies at a height of 1,200 ft. above sea-level, and is connected with the mill, situated near the shore of the lake, by a double-rope tramway. The country rock consists of slate with granite close at hand. The slate is penetrated by dykes and irregular veins of quartz, often sheared and dislocated. Earthy and pulverulent molybdenite is seen on the joint-faces of the quartz and in fine disseminated flakes within it. The ore so far as worked contains about 2 % molybdenite. In 1916, 383 tons of ore were sent to Renfrew for concentration. The mine has been idle since 1917.

The Index mine lying on a ridge between Texas and Cayuse creeks, 15 miles S.W. of Lillooet, in the Lillooet Mining Division, contains molybdenite disseminated along shear planes in granite; one zone has been followed for several hundred feet, but further prospecting is needed. When work first began here in 1916, 8 tons of hand-picked ore assayed 15 % molybdenite [49].

The Molly mine, 8 miles S.E. of Salmo, Nelson Division, West Kootenay district, has been worked by the International Molybdenum Co. of Renfrew, Ontario. The deposit is an impregnation of molybdenite and other minerals in the upper border of a granite stock. The ore-body consists of a zone, from 8 to 10 ft. in width, beneath a chilled border or hard shell or capping of fine-grained granite, characterized by platy or sheeted jointing, closely spaced and parallel to the contact border. Molybdenite occurs along these interlocking joint-planes in reticulated vein-

lets branching and crossing from joint to joint, as well as impregnating the granite between the planes. Pyrite and pyrrhotite are associated with the molybdenite. The granite shell above the ore-zone is dotted through with a few scattered molybdenite grains, whilst the coarser, blocky and diagonally-jointed granite below is impregnated with molybdenite for considerable distances from the ore-zone, which has been traced for 1,200 ft. It is of interest to note that quartzose granite, almost without mica (post-Jurassic), is cut by pegmatite dykes parallel to the ore-zone, and that the joint-planes in the ore-zone dip at low angles away from the centre of the stock [50]. In 1916 about 18 tons of 12 % ore were sent to Renfrew for concentration. Since its discovery in 1913 the Molly mine has shipped 50 tons of molybdenite, but developments ceased in February, 1917.

The Grande Prairie mine, 20 miles south of Ducks and 1 mile west of the Salmon River, Portland Canal Mining Division, is in a region of hornblende-granite intrusive into the Cache Creek quartzite and limestone (Carboniferous). The ore-body is a band of green siliceous rock with much garnet, about 2 ft. wide, and strikes N.–S., dipping about 45° W. It lies at the junction of the quartzite and limestone and has been followed for 300 ft. in open cuts. From 50 to 75 tons of ore have been mined and yielded 1 to 2 % molybdenite in large flakes.

In the Rocher Déboulé mine (mainly copper, with some silver and gold), Rocher Déboulé Mts., Hazelton, in the Cariboo district, molybdenite occurs as small flakes sparsely disseminated through hornblende. Some of it appears to be earlier, and some later, than chalcopyrite. The country rock is a granodiorite intrusive in the Hazelton series (late Jurassic) [51].

The Hazelton View mine, on the west slope of Rocher Déboulé Mts., adjoins the above. The main vein strikes N. 80° E. (true), dips N.W. 55° to 60° in granodiorite, and contains, in order of abundance, arsenopyrite; safflorite ($CoAs_2$); löllingite ($FeAs_2$); molybdenite; native gold, and a little chalcopyrite, in a gangue of actinolite, quartz and some calcite. A 2-ft. dyke of fine-grained granodiorite-porphyry runs close to, and parallel with, the vein, which is 18 in. to 4 ft.

in width. It has been exposed by cuts and stripping for 2,200 ft. horizontally, through an elevation of over 1,100 ft.

The first 3 tons of ore from a shoot in a drift 600 ft. below the top of the ridge gave an assay of 5·20 oz. gold per ton; 4 % cobalt and 22 % molybdenite. A 9-in. streak, 375 ft. from the mouth of the main drift, contained 20 % molybdenum, and the general ore from the rise gave 3 to 4 % molybdenite.

The molybdenite is freely disseminated in the hornblende as small flakes and crystals. It is seldom found in the arsenopyrite. It is earlier than the calcite and later than the gold, arsenopyrite, safflorite and löllingite.

On Timothy Mt., Quesnel Mining Division, Cariboo district, molybdenite occurs in granodiorite. According to J. D. Galloway [48/1917, p. 135] it is disseminated along joint-planes, fractures and slip-planes in that rock, but does not appear to form any definite ore-body or vein. It is found, for instance, in thin scales or plates along the main joints which strike N.–S.

Manitoba

Several promising deposits have of late been reported from the province of Manitoba. Molybdenite in a quartz vein in granite at Herb Lake has been known for some years, and it has also been noted recently in a quartz-chalcopyrite ore-body near the mouth of Hole River, on the eastern shore of Lake Winnipeg.

In 1916 several claims were staked out near Falcon Lake on the Ontario–Manitoba boundary [52] [53]. Long, narrow belts of chlorite- and hornblende-schists, originally volcanic rocks of Keewatin age, form troughs in granite. The granites are of two different ages, the earlier one being grey in colour and foliated, while the later red granite is not foliated: associated with the latter are pegmatites and aplites cutting the granites and schists, and carrying molybdenite. The pegmatites lie parallel or slightly obliquely to the granite-schist contacts, with minor masses nearly at right angles to them. The dykes vary in width from 2 to 10 ft. and occur in groups. They are very varied in texture and consist chiefly of quartz, felspar, muscovite and red garnet, with occasional crystals of beryl. The molybdenite forms prisms 2 or 3 in. thick, or coarse radiating

groups of lamellæ of even larger size: in one place it occurs in a granular and massive form and it is also seen as small grains and flakes in the aplites. One quartz vein carries felspar and lamellar masses of molybdenite with a little bismuth. The weathered surface as a rule is poor; on opening up by blasting, some crystals, up to half a pound in weight, were secured, and a high-grade product could easily be obtained by hand-picking. The molybdenum content of the pegmatites probably amounts to not more than 0·1 to 0·2 %

New Brunswick

In the well-known wolfram deposits of Burnt Hill Brook, Miramichi, New Brunswick, molybdenite is found in fairly considerable amount in veins in slate up to 2 ft. wide. It is also said to exist near Gaspereau Station in Charlotte Co., and on Trout Brook in the parish of Pennfield; also near Bathurst on the Nipisiguit River, in Gloucester Co.

Nova Scotia

At Jordan Falls, in Shelburne Co., Nova Scotia, veins and stringers of milky quartz with tourmaline and molybdenite are seen cutting staurolite-schist and granite with pegmatite dykes rich in tourmaline: the veins, which strike N.E.–S.W., are up to 2½ ft. in width. No development was recorded up to 1911, and the deposit has probably no commercial value.

Near New Ross, in the Chester district, Lunenburg Co., ores of molybdenum, tungsten and tin are found in several places in a two-mica granite. The molybdenite is scattered through the rock in thin plates, from ⅛ to ⅜ in. in diameter. This rock is apparently known only as loose boulders. West of New Ross molybdenite occurs in a thin zone, ½ to 2½ in. wide, parallel to a N.E. vertical joint in grey muscovite-granite. The rock contains a little purple fluorspar. This deposit was tested at the surface about 20 years ago. On a third occurrence, 2 miles N.W. of the latter, some work was done in 1907. Molybdenite is here found with a large variety of other minerals, including cassiterite, wolfram and monazite, in very coarse pegmatites connected with a muscovite-granite.

In Cape Breton Co., near Gabarus Bay, Cape Breton Island, a few miles west of Louisburg, stringers of quartz in a felsitic

rock carry molybdenite. The best locality is near Eagle Head; another locality is 4 miles S.E. of Big Pond, near Glengarry Post Office. Dykes of red granite in slate here carry occasional spots of molybdenite [44].

Ontario

The molybdenite deposits of the province of Ontario show similar geological relationships to those of Quebec, described below (p. 29). Occurrences, many of them very small and unworkable, have been recorded in the following localities: in the townships of Somerville and Laxton, Victoria Co.; Cardiff, Harcourt and Lutterworth, Haliburton Co.; Sheffield, Addington Co.; Anstruther, Peterborough Co.; Miller and Olden, Frontenac Co.; Lynedoch, Matawatchan, Brougham, Sebastopol and Ross, Renfrew Co. The productions of molybdenite concentrate in Ontario in the years 1916–18 were 24,562; 77,517, and 47,614 lb., a total of about 75 short tons. There was no production in 1919.

The most important producer in Ontario was, till 1918, the Renfrew Molybdenum Mines Co., Ltd., at Mt. St. Patrick, 18 miles S.W. of Renfrew, in Brougham Township. Here several shafts were sunk in fissured gneiss, mineralized by sulphides and associated with contact pyroxenites. Ore also occurs at points where pegmatites cut the gneiss and limestone. The contacts are very ill-defined and the mineralization is diffused.

The Hunt mine of the Renfrew Molybdenum Mines, Ltd., is in Brougham Township, 11 miles from Ashdod Station on the Kingston and Pembroke Railway. The ore-body lies at the contact of limestone and granite: it has been traced for 400 ft. at the 40-ft. level, but at greater depths the contact appears to turn in under the granite for about 130 ft. It is, however, again encountered at a greater depth in the same shaft; this may be due to faulting. The ore deposit is of the contact-pyroxenite type and well-defined, at the junction of red granite and Grenville limestone. The concentrating plant produces about 300 lb. of concentrate per day from 1% ore.

At the Chisholm mine in Sheffield Township, Addington Co., 5 miles from Wilkinson Station on the Canadian Pacific Railway, an iron-stained pyroxenite carries pyrite, pyrrhotite and

molybdenite, forming a mass of about 300 by 200 ft. and of unknown depth, at the contact of red granite and Grenville limestone.

The Lillico Burrows mine in Monmouth Township, Haliburton Co., $1\frac{1}{2}$ miles west of Tory Hill Station on the Irondale branch of the Canadian Northern Railway, shows red granite, gneiss and pegmatite with pyroxenite carrying pyrite, pyrrhotite and molybdenite, all in flat-lying beds. In the same neighbourhood are one or two other small deposits of similar type carrying a fair amount of low-grade ore.

In Harcourt Township, 3 miles north of Wilberforce Station, Haliburton Co., veins of molybdenite, pyrite and pyrrhotite are found in granite, pyroxenite and limestone. In Cardiff Township a promising deposit of molybdenite with chalcopyrite has been noted at a contact of pyroxenite and mica-scapolite rock.

At Mud Turtle Lake, in Laxton Township, Victoria Co., three claims show a promising body of decomposed pyroxenite carrying pyrite and molybdenite (1 to $1\frac{1}{2}$%), but the ore-body dips under the lake and might be difficult to work. Molybdenite appears to be frequently met with in the limestone belt for a distance of 15 miles to the S.E.

In 1916 production on a commercial scale was recorded from the following localities in Renfrew Co.: The Jamieson mine in Lynedoch; the Spain or Legree mine in Griffith Township; properties in Brougham Township operated by the Renfrew Molybdenum Mines Co., Ltd., by vacuum oil flotation with a total output of about 1 ton of concentrate per week; and the Ross mine in Brougham Township, belonging to Molybdenum Ltd., of Montreal.

Quebec

During recent years by far the greatest part of the Canadian production of molybdenite has come from the western half of the province of Quebec and the adjoining districts in Ontario; in fact the Moss mine near Quyon, Quebec, was probably for several years the largest and most important single molybdenite mine in the world. All these deposits possess the same general characteristics, being connected with intrusions of Laurentian granite into the Grenville sedimentary series, consisting largely

of crystalline limestones and dolomites, and with the later pegmatitic phases of the Laurentian.

In the typical area of Pontiac Co. three principal types of deposit can be recognized, as follow [54]:

(*a*) Basic segregations in the Laurentian granites and syenites;

(*b*) Pegmatite dykes of the Laurentian series;

(*c*) "Contact deposits" in metamorphic limestones of the Grenville series (contact-pyroxenites).

The first type is well seen in the No. 1 shaft of the Dominion Molybdenite Co. at Quyon, Quebec, as hereafter described; the second type is fairly common and sometimes contains considerable quantities of molybdenite. The third type is perhaps the most widely distributed and may be described in general terms as follows: Lenticular masses of limestone belonging to the Grenville series have been altered by contact with the gneissose hornblende-granites of the Laurentian. There has been a good deal of assimilation of limestone by the granite and diffusion of silica from the granite into the limestone, giving rise on the one hand to pyroxene-granite, syenite and gabbro, and on the other to rocks consisting mainly of lime silicates, the so-called contact-pyroxenites. The ore-bearing rock consists mainly of lime-pyroxenes with scapolite and sulphides, and often contains sphene. This type is very similar to the skarn (*see* p. 3) of the Scandinavian geologists, which is frequently ore-bearing [55].

To the three main types just described, M. E. Wilson adds a fourth: Veins of pyrite, pyrrhotite and quartz in granite-gneiss. The veins are one foot or less in thickness, and are irregular and discontinuous. In the Spain property the veins are so close together that the whole mass can be mined, although it contains only about 0·5 % molybdenite [56].

As before stated, the largest producer of molybdenite in Canada and probably in the world from 1916 to 1918 was the Moss mine of the Dominion Molybdenite Co., in Lots 9 and 10, Range 7, Onslow Township, Quyon district, Pontiac Co. It was the only producer in Canada in 1919. Here two types of ore-body were worked; one is a pegmatite dyke, while the other is described as segregations in granite: these are probably large xenoliths more or less completely assimilated

by the granite. In the No. 1 shaft the country rock is a finely grained hornblende-biotite-granite enclosing a dome-shaped mass of biotite-syenite measuring about 130 ft. by 60 ft. This is the ore-body and contains pyrite, pyrrhotite, molybdenite, pyroxene, tourmaline and fluorspar; a pegmatite dyke cutting the syenite also contains a little ore; some smaller segregations of more basic character, which may be described as mica-diorite, carry less ore. The molybdenite occurs in thin seams, lumps and disseminations, and is very varied in its distribution.

Work was begun at this mine in 1915 by the Canadian Wood Molybdenite Co., the ore being shipped to Denver for treatment by the Wood water flotation process. Later it was sold to the Dominion Molybdenite Co. From March 1916 to March 1917 the output was about 5,500 tons of 2% ore, which was mined by open cuts and concentrated by a Wood flotation plant in a mill of 60 tons capacity [57] [58] [59].

Occurrences of molybdenite are known along the Gatineau Valley and in Pontiac Co., in the townships of Egan, Alleyn, Aldfield, Huddersfield, Aylwin, Eardley, Masham, Onslow, Thorne, Wright, Bouchette, Clarendon, Litchfield and Waltham; also near Lake Kewagama in Northern Pontiac [60].

Among the many molybdenite prospects of Quebec the following may be mentioned as of some promise: In Egan Township, Pontiac Co., 18 miles north of Maniwaki Station and 80 miles north of Ottawa, molybdenite occurs in plates up to 2 in. across in parallel stringers in a green pyroxene rock associated with gneiss, schist and crystalline limestone. In Aldfield Township irregular masses of sulphides, principally pyrite, pyrrhotite and molybdenite, occur in a greenish pyroxene rock [44]. At Squaw Lake in Huddersfield Township, 25 miles N.E. of Shawville, the Canadian Wood Molybdenite Co. worked a contact deposit in a belt of Grenville limestone adjoining grey granite, and invaded by pegmatites; this deposit is exposed for about 1,500 ft. along the strike and shows a width of about 15 ft. of milling ore. The Tipping mine in Clarendon Township, 8 miles N.E. of Shawville, shows a contact deposit between limestone and gneiss near red granite; a few tons of ore in the dump showed less than 1% molybdenite. The Davis property in Litchfield Township, 6 miles N.E. of

Fort Coulonge, has been worked from small shafts in gneiss, crystalline limestone and pyroxenite, with grey granite-gneiss cut by pegmatite.

In Eardley Township, Ottawa Co., Quebec, the Wood-Ormond mine, 3 miles from Breckinridge station, shows molybdenite in an inclusion of dark hornblendic rock in granite; this appears to be of small extent. The Chaput-Payne mines in Eardley and Hull townships, on the face of the southern Laurentian escarpment, are in a mass of Grenville rocks, caught up in Laurentian granite and penetrated by pegmatites. There has been extensive development of pyroxenite, and molybdenite is seen in places in coarse flakes, which can be hand-sorted. There appears to be a considerable tonnage of low-grade ore, carrying probably under 1% molybdenite.

In Timiskaming Co., near Kewagama Lake, some promising deposits of molybdenite ore, associated with bismuthinite, have been worked on a fairly large scale. In the mine of the St. Maurice Syndicate on Indian Peninsula, Kewagama Lake, in Preissac Township, 20 miles S.W. of Amos on the Transcontinental Railway, is worked a series of veins of quartz and greenish mica with molybdenite. The peninsula, which rises 200 to 300 ft. above the lake, consists of a mass of Keewatin rocks invaded by granite, with aplite dykes and quartz veins, the whole being cut by later dolerite dykes. There are two types of ore-body:

(*a*) Veins from 2 to 5 ft. wide, striking N.W.–S.E. and very persistent, with the molybdenite chiefly segregated in the footwall. The molybdenite content appears to be less than 0·5%.

(*b*) Masses of quartz at the contact of granite and aplite; the contact zone is about 100 ft. wide and on the eastern part of the Sweezey claim it carries molybdenite with mica, especially along the walls or in veinlets across the quartz. The grade is apparently below 1%. There are many small open cuts and shafts up to 20 ft. deep. One thousand tons of rock yielded 50 tons of 1% ore, and some picked samples contained up to 7%. This seems a promising prospect [45/p. 113].

At the Height of Land mine on the west side of the Kewagama River near its outlet from Kewagama Lake, near the township of Villemontel in the Abitibi district, mica-schist is cut by a peg-

matite dyke from 30 to 50 ft. wide, consisting of quartz and muscovite with felspar, pyroxene, pyrite, bismuthinite, fluorspar and beryl, carrying molybdenite in six-sided crystals from ½ to 1½ in. across [44]. As a whole the ore is of very low-grade, perhaps of 0·1% molybdenite, but some good samples have been obtained by hand-picking.

The molybdenite deposits of La Corne Township, Abitibi, have been described by Adhémar Mailhiot [61]. On the Eureka claims are a series of pegmatite veins along the contact between a biotite-granite and a mica-schist, striking. N. 70° to 80° E., and dipping S. 40° to 70°. They constitute a system of close parallel veins disposed in echelon over a cross distance of about 600 ft. They vary from a few inches to several feet in thickness. Mineralization took place in sericite-schist, which forms lenticular masses along fissures in the pegmatite. The pegmatite is irregularly distributed from the centre of the walls. The molybdenite is fine-grained in the sericite. Coarse molybdenite occurs lining pockets and impregnating the quartz and felspar of the pegmatitic veins. There is, besides, a series of small stringers, of varied direction, from 1 to 15 in. in thickness, containing molybdenite, fluorspar and molybdite. Where these stringers cut the granite, sericite is very abundant, having molybdenite disseminated throughout; on the other hand, where they cut black mica-schist, there is no sericite, but only quartz and mica. The veins in 1919 had been prospected to a depth of 45 ft. only.

At Manikuagan Bay, in the Saguenay district on the north shore of the St. Lawrence, a bed of quartz 6 in. thick, interstratified in a coarse white gneiss with garnets and black mica, contains molybdenite in flakes 12 in. across and ¼ in. thick. Another similar vein described as cutting a black greisen carries nodules up to 3 in. in diameter. Similar veins carrying flakes and crystals of molybdenite up to 12 in. across are seen cutting mica-schists in the same neighbourhood, as well as on numerous islands for 6 or 8 miles east of the Mekattina River. Near the mouth of the Olomanoshibo River, 100 miles east of the foregoing, lies McKenzie Island, which is made up of grey mica-sillimanite-gneiss interbanded with strings of intrusive pink pegmatites. The bands, when of quartz, carry molybdenite [44].

Productions of molybdenite concentrate in Quebec in the years 1916–19 were 129,275; 226,739; 342,296, and 83,002 lb. respectively, a total of about 391 short tons. There was no production in 1920 [12].

In 1918 all the ore produced in Canada was concentrated in Canadian mills and marketed either as concentrate, molybdic acid, ammonium molybdate or as ferro-molybdenum, for the manufacture of which two electric furnace plants have been erected: the plant of the Orillia Molybdenum Co. at Orillia, and that of the Tivani Electric Steel Co. at Belleville, both in Ontario. The combined output of these two companies in 1917 was about 75 tons of ferro-molybdenum.

The concentrating plants in Canada are as follow:

Dominion Molybdenite Co., Ltd., at Quyon, Que.

St. Maurice Mines, Ltd., Indian Peninsula, Timiskaming, Que.

International Molybdenum Co., Renfrew, Ont.

Mines Branch Plant, Ottawa, Ont.

Molybdenum Products Co., Haliburton, Ont.

Renfrew Molybdenum Mines, Ltd., Mt. St. Patrick, Renfrew, Ont.

Steel Alloy Corporation, Dacre, Renfrew, Ont.

Molybdenum Mining and Reduction Co., Alice Arm, B.C.

Newfoundland

In Newfoundland molybdenite has been found at Rencontre, on the north side of Fortune Bay in the south, to the west of Deer Lake in the west, and on the west side of Baie Verte in the east. According to F. J. Stephens it occurs in irregular veins of quartz in granite, and also disseminated through the rock [62/p. 200].

Leeward Islands

A sample of molybdenite from an old tailing heap of an abandoned copper mine at Virgin Gorda, Virgin Islands, Leeward Islands, West Indies, was examined at the Imperial Institute in 1907, and yielded the following percentages: Molybdenum,

48·93; iron, 3·32; sulphur, 32·20; silica, 12·15. The material contained some free quartz [24].

AUSTRALASIA

AUSTRALIA

Molybdenite is found in considerable quantities, associated with tin, tungsten and bismuth in many parts of the great mineralized belt of Eastern Australia, from the north of Queensland to Tasmania. This belt consists of sedimentary and volcanic rocks of Palæozoic and older date, which were invaded during Permo-Carboniferous times by great masses of granite, and the mineralization is due to these intrusions. The most important molybdenite deposits are found in Queensland and New South Wales, which in recent years between them have provided about half of the world's output of molybdenum ore. The existence of the ore in quantity has long been known, but for many years it was regarded as a worthless by-product in tin and bismuth mining. Production on a large scale began about 1902, and the industry has recently developed considerably.

The production of molybdenum in Australia by states of recent years is shown in the following table:

Molybdenum Production in Australia [1]

(Long tons)

	Queensland.		New South Wales.		Victoria.		Western Australia.
	Concentrate.	Estimated Mo. content.[2]	Concentrate.	Estimated Mo. content.[2]	Concentrate.	Estimated Mo. content.	Concentrate.[3]
1915 . . .	97	52	32	17	—	—	—
1916 . . .	81	44	54	29	—	—	—
1917 . . .	111	57	70	36	—	—	14
1918 . . .	110	56	93	47	6	3[4]	5
1919 . . .	118	60	66	34	78	43[4]	7
1920 . . .	29	15	40	20	48	23[4]	0·5
1921 . . .	9	—	—	—	—	—	—

[1] *Mines Repts.* of the various states.

[2] Molybdenum content of concentrate taken at 54% in 1915 and 1916, and 51% in 1917–20.

[3] Molybdenum content low.

[4] *Mineral Industry*, 1920.

New South Wales

The molybdenite output of New South Wales comes almost exclusively from two widely separated districts; from New England in the N.E. and from the Whipstick area in the S.E. In these two areas six different classes of deposit can be recognized—namely, pipes, aplite segregations, pegmatite segregations, felspar veins, quartz veins and contact deposits. All these are intimately associated with one or other of the different types of granite of late Permo-Carboniferous age, which are intruded into the older sedimentary and volcanic rocks. Most of these granites are more or less mineralized, containing tin, tungsten, bismuth and molybdenum in varying proportions. Most of the important molybdenite deposits are found in association with a coarse, even-grained, non-porphyritic granite, described as "sandy" by the Australian geologists. This seems to refer to the character of the superficial deposits formed by weathering of the rock. The silica percentage is not very high, usually about 72%, whereas the tin and wolfram granites are much more acid. This statement, however, refers only to the main mass of the granite. The molybdenite-bearing ore-bodies even in this type are for the most part very siliceous segregations of pegmatitic character, or even pure quartz-veins.

By far the most important of these deposits occur in peculiar structures called pipes, which are essentially cylindrical portions of the granite occupied by highly siliceous material, which appears to be mainly of secondary or pneumatolytic origin, formed possibly in part by alteration, silicification and mineralization of the granite by escaping vapours or solutions during the later stages of cooling. It is not clear what agency determined the exact position and direction of the pipes, but it may have been in part the jointing of the granite, as shown by the prevalence of more or less rectangular bends in the pipes, the so-called "step and tread" structure. Inclined pipes usually dip towards the granite contact.

These inclined pipes also show another interesting feature, in that the arrangement of the minerals in them frequently suggests that their formation is due to the flow of solutions.

The richest deposits of bismuth ore are commonly found in what is known as the "gutter" of the pipe, that is to say in the portion that would be occupied by a liquid running down an empty pipe in that particular position, and the molybdenite often forms a layer above this. It is improbable that mineralizing vapours would lead to this pecularity.

Five different kinds of pipe-fillings have been recognized, as follow: Quartz, pegmatite, granite, mica-garnet and garnet, but these naturally grade into one another. The quartz pipes appear to represent the most complete replacement of the granite, while the granite pipes are but slightly altered: as to the origin of the garnet in the pipes little is known. The few contact-deposits rich in molybdenite also contain much garnet.

The more important deposits of molybdenite in New South Wales may, as a matter of convenience, be classified as follow:

(1) *New England District:*
Wilson's Downfall, Rocky River or Wunglebung, Bolivia, Deepwater, Glen Eden, Kingsgate, Yarrow Creek, Booralong or Baldersleigh, Attunga and Moonbi, Warrell Creek.

(2) *Yetholme District:*
Mount Tennyson, Gemalla, Tarana.

(3) *Whipstick District:*
Jingera, Mount Metallic, Black Range, Tantawanglo.

Of these the Kingsgate area is by far the most important at the present time. Details of this and others in the New England district follow:

Several small occurrences in the parishes of Ruby, Carry and Wylie, near Wilson's Downfall, show molybdenite either as scattered flakes in granite or with wolfram and bismuth in aplites and small quartz veins. On Waterson's Claim, Maryland, is a vertical pegmatite pipe 9 or 10 ft. in diameter in the coarse acid granite, which is here intruded as bosses into the older porphyritic granite with tin and wolfram.

The Rocky River or Wunglebung deposits, in a deep and wild valley 26 miles S.E. of Tenterfield, consist of a group of pipes in a very siliceous granite with a marginal facies of peg-

matite, aplite, greisen and quartz, intrusive into a dark porphyry and Permo-Carboniferous sediments. All the molybdenite occurs near the contact between the acid granite and the porphyry. At Boundary Creek molybdenite and wolfram are fairly abundant in patches of coarse pegmatite, probably the outcrops of pipes; these are worth investigation. At Goodwin's Claim several pipes of coarse granite carry much bismuth in the gutter of the pipes, the molybdenite forming an inner ring above, with wolfram outside it. Some of these pipes are very promising, especially those in the Roberts and Heiss Claim. This district is much handicapped by poor communications. In 1919, in the Tenterfield Division, a total of 370 tons of ore was treated for 91 cwt. of molybdenite (£1,365). In 1920 only 3 tons (£410) was produced [63].

In the Bolivia locality, which lies to the west of Deepwater, is a large granite mass lying above the general level of the neighbourhood. This is really an eastern extension of the Great Mole Tableland granite, which has yielded so much tin and tungsten, and comprises several different granite intrusions of varied character. The more westerly Angoperran granite is rich in tin and tungsten and carries comparatively little molybdenite, while the Booroo granite to the east is more basic and shows good pipes of molybdenite like those of Bow Creek and Kingsgate. The two granites are separated by a ridge of quartz-porphyry. The molybdenite occurs in the Booroo granite in pipes of quartz and felspar in varying proportions. The most promising occurrence is on Key and Parry's claim, in which is a pipe of bluish-white quartz and pegmatitic material with felspar and soft mica, and containing abundant molybdenite in flakes and masses.

The situation of the Deepwater mining area is in Co. Gough, near the last described group, but east of the town of the same name. Here there are two types of deposit: (*a*) Pipes in a coarse, rather basic granite near its intrusive contact with quartz porphyry; (*b*) Greisen and pegmatite veins in a coarse, very acid granite near its contact with claystone. The Allies Consolidated Molybdenite Syndicate works a pegmatitic pipe of glassy quartz and felspar 6 miles east of Deepwater, about 10 ft. in greatest diameter, with flat-lying branches. At Bow

Creek pipes of quartz and pegmatite in granite are worked by the same syndicate, and carry molybdenite in hexagonal crystals and rosettes up to 2½ in. across. The Syndicate in 1919 produced 18·7 long tons of concentrate containing 92 % molybdenite (£9,440). The 1920 production was valued at £725. The total production of the Deepwater Division in 1919 was 38 tons (£19,480) from 770 tons of ore. In 1920 production was 12½ tons (£2,800).

The Glen Eden mine is in the parish of Boyd, Co. Gough, 12 miles north of Glen Innes. A mass of very siliceous porphyry is penetrated by numerous quartz veins over an area 1,000 yd. long and 400 yd. wide. It yields chiefly wolfram, but molybdenite is common in large flakes in greisen and quartz. There are many rich patches of ore, which are, however, hard to find. In 1920, 40 tons of ore yielded 7¾ cwt. of molybdenite, worth £141.

The deposits at Kingsgate, the largest and most important in New South Wales, are 20 miles east of Glen Innes, on a plateau with a general altitude of about 3,750 ft., with scattered peaks of tin-bearing granite reaching to 5,000 ft. and intersected by many deep valleys. The ore-bodies are oval or circular pipes of quartz, either vertical or more or less inclined in the granite, which is intrusive into altered porphyries. When inclined, they dip towards the contact, and often show the step and tread conformation previously mentioned. Sometimes the pipes are as much as 30 or even 40 ft. across, but more commonly about 10 ft. Occasionally they branch, either upwards or downwards. Some have been followed for as much as 500 ft. along the dip. In 1920 the Kingsgate Molybdenite Co. from 2,294 tons of pipe formation won 8¾ tons of molybdenite concentrate (£4,370).

On the Yates property about 50 pipes are known, and most of these have been more or less developed. One of the largest, the Old 25, is about 40 ft. in diameter.

Molybdenite, bismuthinite and a little bismuth are especially prevalent on the underside or "foot-wall" of the pipes. This is the case for example with the pipe known as "Arsenic Blow," and at the lowest point or "gutter" of the foot-wall the felspars of the granite have been altered in great masses to nests and

flakes of soft mica. Immediately above this lies a quartz mass, brown, compact, or cavernous, of fine texture and containing native bismuth with a little molybdenite. Black quartz crystalline or massive, cavernous or compact, fine and coarse in texture, with molybdenite, overlies this in turn. This association passes upwards by stages into white or grey quartz, either massive or in large crystals, either well-jointed and brittle or compact, or containing caverns as much as 10 ft. in length [64/p. 103].

One of the most famous examples is the Old 45 or Sachs' pipe (now the property of the Glen Innes Molybdenite and Bismuth Syndicate); this was worked in the early days for bismuth, but was abandoned because of the abundance of the then worthless molybdenite. It has of late produced much molybdenite. In 1902 the ore from one large chamber of about 50 by 20 ft. is said to have yielded £30,000 in molybdenite and bismuth. This mine in 1916 was over 300 ft. deep measured along the dip, and the ore was then concentrated by crushing and rolling, and by passing over shaking screens and Wilfley tables.

The Sachs' pipe appears, like a good many others of the Kingsgate pipes, to be associated with joints containing molybdenite. A peculiar sericitization and silicification of the granite characterizes the pipe all the way down [64/p. 109]. Andrews regards this and other pipes as replacement deposits formed along joints or planes of weakness.

The Sachs of Kingsgate Syndicate works the Wet Shaft and Goodwin's pipes. The Wet Shaft pipe, which is about 8 ft. across and inclined, shows four distinct layers, as follow: On the foot-wall, granite with sericitized felspars; then granular cavernous quartz with much bismuth and little molybdenite, which, in turn, is overlaid by brown or smoky quartz rich in molybdenite, while the rest of the section, rather more than half, is occupied by white quartz with some molybdenite flakes.

There are several other claims and workings in this area, such as Speckhardt's, Lancaster's, Marshall's, Murphy and Wilson's, and Cahill's: not much work has been done on these. It has also been proposed to dredge the old tailing from Sachs' mill, now lying in Yarrow Creek.

Yarrow Creek is in the parish of Yarrow, 2 miles south of Kingsgate, and several pipes have been found in this locality on and near the same granite contact. These were not being worked in 1915, but some good ore was lying on the dumps from trial holes.

The Mount Booralong molybdenite mine is near Guyra, Co. Hardinge. The formation consists of coarse siliceous granite and quartz-porphyries with patches of aplitic and pegmatitic granite, containing, in places, flakes of molybdenite as an original constituent, and nests of pyrite, arsenopyrite and chalcopyrite, and a little bismuthinite. There are shallow surface workings and a small treatment plant, but no defined channel or ore-body has so far been located in the workings, hence it is difficult to understand why a treatment plant was erected here [65].

Laura Creek is 9 miles from the last-named place in the parishes of Abington and Russell. Molybdenite occurs here in small flakes in pegmatitic dykes and tongues of granite, which are intrusive into volcanic rocks and Permo-Carboniferous sediments.

At Attunga and Moonbi a porphyritic hornblende-biotite-granite is intruded into Devonian sediments, which are again penetrated by an acid granite with pegmatitic patches and veins carrying molybdenite. Two veins show molybdenite associated with some scheelite and chalcopyrite, but all are small and not very promising.

At Warrell Creek or Nambucca, Co. Raleigh, are quartz veins in granite which contain molybdenite often in crystals having a stellate arrangement. Its occurrence is very patchy, but some rich specimens have been found.

In the Yetholme district the molybdenite deposits lie in the eastern part of the parish of Yetholme and in the western part of the parish of Eusdale, Co. Roxburgh, not far from Bathurst [66].

In the western portion the important deposits of Mt. Tennyson lie in the large valley of the Fish River, one of the chief head waters of the Macquarie River, at a height of about 3,800 ft., in a rather inaccessible district with bad roads, though not very

far from a railway station. A large batholith of granite has been intruded into Lower Palæozoic sediments, including limestones and sandstones with claystone and interbedded quartz-porphyry flows. Most of the beds are intensely silicified within the contact aureole, and the limestone has been recrystallized to sugary marble. The molybdenite is chiefly found in a garnetiferous zone from 2 to 30 ft. thick, composed of amphibole, epidote, calcite, quartz and yellow and brown garnet; there are also some rounded masses of wollastonite with cores of marble. The molybdenite is scattered as flakes and "paint ore" throughout this zone, which forms an immense mass of low-grade ore. This is a remarkably interesting example of a contact or metasomatic deposit.

Several different claims have been prospected here. Boyd's Blocks contained a very large quantity of ore which has been said to average 1·8 % molybdenite, but it is doubtful whether this was really a representative sample. Buckridges's Block is estimated to contain 4,000,000 tons of garnet rock, while Kirk and Wade's Block, Field and Gerrard's Blocks, and the ground taken up by the Lithgow Co. and Yetholme Molybdenite Options, Ltd., are also very promising. The Mammoth mine, which was a producer in 1919, was temporarily closed down on account of reconstruction in the middle of that year.

The Gemalla deposits in the parish of Eusdale are very similar in character, comprising a red garnet rock with green pyroxene, epidote, calcite, a little blende and quartz: the ore is of fairly high grade. The Tarana deposits, also in Eusdale parish, are of quite a different character, being in pegmatites at the contact of granites and sediments and of low grade: they are probably unpayable.

The Whipstick district lies in the S.E. corner of New South Wales, between Pambula and Bombala, and about 18 miles from the port of Merimbula. The Whipstick Mines, Ltd., in 1919 produced 4 tons 18 cwt. of concentrate (£1,672). In 1920, after producing 2 tons, it suspended operations.

The country rock of the district as a whole consists of Devonian sediments penetrated by granite and overlain by Tertiary basalt flows. The granite is of two types, the earlier

being dark in colour and rich in hornblende, while the younger muscovite granite is much more acid.

In the Metallic Mines are pipes in granite of which the uppermost 20 to 30 ft. consists of a manganiferous gossan with molybdic and bismuth ochres, underlain by clean sulphides in the unweathered granite below; there are also some pipes of quartz or garnet rock, carrying much bismuth, partly in the form of telluride, with some silver and gold. Some rich bunches of molybdenite have been found, and two trials on about 1 ton of ore by the Minerals Separation flotation process with eucalyptus oil, showed a content of 5·14% molybdenite. The ore is hand-picked at the mine and then carted to the concentration plant, where it is hand-fed to a battery of 15 stamps, crushed to 20 mesh, and passed to three shaking tables, which catch the bismuth: the rest passes by launders to a settling pit, whence it is elevated to the mixer of a 12-in. Minerals Separation flotation plant, which gives a concentrate of 82–90% molybdenite.

At Black Range, Bega, are quartz veins 15 to 40 in. wide, which are found in the very acid marginal facies of a late Devonian granite: they consist of dense white quartz with 1·5 to 2% of very finely divided molybdenite.

At Tantawanglo, on the escarpment edge of the great Monaro Plateau, near Bombala, 8 miles from Cathcart, an acid granite shows patches of aplite and pegmatite sometimes several hundred yards long, with flakes of molybdenite forming a very low-grade ore. (The above descriptions of the New South Wales deposits are taken largely from memoirs by E. C. Andrews [64/p. 26] [67].)

The total production of molybdenum concentrate in New South Wales to the end of 1920 was 1,144 long tons.

Northern Territory

The wolfram and molybdenite deposits at Yenberrie, 4½ miles S.W. of Horseshoe Creek of Northern Territory, have already been described in the Imperial Institute monograph on *Tungsten Ores* (1920, p. 42). The two minerals occur in aplite dykes, and in strike fissures connected therewith,

traversing a hornblende-biotite granite. Molybdenite happens to be the chief ingredient of one very narrow aplite dyke, and the surface quartz is freely pitted with the casts of molybdenite crystals. The primary ore carries, in order of formation, wolfram, molybdenite and arsenopyrite, with a little copper and bismuth [68].

A little molybdenite has been found in two of the wolfram-bearing veins of Hatches Creek, the country being described as a dioritic rock [69].

Queensland

Until quite recently Queensland was probably the largest producer of molybdenite ore in the world.[1] By far the greater part of the production comes from the northern part of the State, but there is a small area in the extreme S.E. which is a direct continuation of the New England molybdenite field of New South Wales (*see* p. 36), and shows precisely similar features. Although much the less important it will be well to describe this area first for the sake of continuity.

The Stanthorpe molybdenite field lies in Co. Bentinck a few miles from the southern boundary of Queensland, some 20 or 30 miles north of Tenterfield in New South Wales. The ore occurs in an acid phase of the Stanthorpe granite, as numerous small scales and flakes along the master joints of the granite, also in a pegmatite dyke and in small quartz stringers in the granite.

The largest production from the Stanthorpe field was 4½ cwt. (£125) in 1915. In 1919 the only production of 3½ qr. (£22) came from Wallangarra, in the south of Co. Bentinck. In 1920 there was no production. A promising discovery at Carpenter's Gully in the same district was abandoned owing to absence of water.

In the Ballandean area molybdenite is recorded at Chalmers Claim on the left bank of the River Severn, parish of Ballandean, Co. Bentinck, at the contact of granite with slates and tuffs of the Lower Bowen series (Permo-Carboniferous). A very large dyke of aplite, 80 to 100 ft. wide, cutting the slates shows a central mass of quartz, about 50 ft. across and more or less circular in plan. This carries patches of molybdenite through-

[1] The U.S.A. output is largely composed of wulfenite concentrate.

out with occasional rich bunches as seen in an open-cut working. Several other claims in the neighbourhood are rather similar. A little tin, tungsten and bismuth are also found in the district [70] [71].

The principal molybdenite deposits of Northern Queensland are at Wolfram and Bamford in the Chillagoe district. Molybdenite is also mined at Sandy Tate River (Chillagoe), at Kidston in the Etheridge Mineral Field, and at Ollera Creek (Star Mineral Field), near Townsville. Other areas in the Chillagoe and Herberton fields and at Rosedale, N.W. of Bundaberg, have also been prospected [72]. The productions of molybdenite concentrate in the Chillagoe mining district in 1919 and 1920 were 73½ and 23½ tons.

There is a notable difference between the deposits of Northern Queensland and those of New South Wales. Whereas in the latter state the principal tin, wolfram and molybdenum-bismuth deposits occur in localities and under conditions quite distinct from each other, and are associated usually with different types of granite, in Queensland wolfram, molybdenite and bismuth minerals occur together in all the mines, although the chief tin deposits are separate. Little information of a detailed character is to hand concerning the metalliferous granites of Queensland, but there is no doubt that, like those further south, they are of late Permo-Carboniferous age [64/ p. 17].

Molybdenite mining in Queensland started in the Wolfram area, then known as Wolfram Camp. The ore was at first regarded as a worthless by-product in bismuth mining, and no market existed till 1900: in that year 11 tons of ore sold for £51. At the end of 1902 the spot price per ton was £200 for concentrate, and in 1901 and 1902 the outputs were 26 tons and 38 tons respectively. Most of this came from a small area at Jeff's Camp, Wolfram.

The molybdenite deposits of Northern Queensland are invariably found near the contact of intrusive granites with older rocks, most commonly in the granite itself, but occasionally in the altered sediments. By far the most common type of occurrence is in pipes similar to those of New South Wales, though molybdenite is also known as disseminations in the

granite or along open joints, as well as scattered through sediments. There seems to be no doubt that the pipes have been formed by the escape of solutions or vapours along open joints or lines of weakness in the cooling granite during the latest stages of solidification. In many cases the lie of the pipe is no doubt determined by the intersection of two joints, but it is not clear why, when inclined, they always dip towards the margin of the granite.

In the Wolfram field (altitude, 2,500 ft.) molybdenite is found in payable quantities in a gangue of clear white quartz in joints and fissures in a grey biotite-granite, with native bismuth and a little bismuthinite; at the deeper levels arsenopyrite and pyrite also appear. The molybdenite is generally in large masses, easily separated by cobbing, but its distribution is patchy and the deposits are very irregular, sometimes mere veins in the granite, and seldom well-defined lodes with clean walls.

At Jeff's Camp the outcrops are often circular or oval masses of quartz with molybdenite, bismuth and wolfram. In depth these develop into pipes without well-defined walls, and veins run into the granite for a short distance. Most of the ore occurs along horizontal cracks in the pipes. Molybdenite usually begins to appear some 20 or 30 ft. from the surface, having apparently been weathered away in the uppermost part of the pipe. This area includes Shaw's Claim, Kenrick's Claim, Gillian's Claim and others [73].

At the present time the chief producers in the Wolfram field are the Larkin, the MacIntyre, and the Murphy and Leisner mines. On the Larkin property several irregular pipes have been worked in the greisen under the slate contact, down to a depth of over 100 ft. The McIntyre pipe has been followed down about 250 ft.: near the surface it has a low pitch, increasing in depth to about 45°.

The Murphy and Leisner, which is the principal producer, adjoins the Larkin on the slate-granite contact. In it is worked a rich ore-body in the form of a pipe of varied, but usually steep, pitch: the average diameter of the stope is about 20 ft. and in three years the mine produced about 100 tons of molybdenite concentrate [74].

At the Top Camp workings several claims contain fairly rich patches of molybdenite, for example, Kelly's Claim, now abandoned.

A few years ago the Thermo-Electric Ore Reduction Corporation of Luton, England, acquired most of the important holdings in the Wolfram field and initiated a certain amount of development, including the purchase of mine machinery in Cornwall for transport to Australia. In 1916 and 1917 the output of molybdenite concentrate amounted to 1 or 2 tons a week for the whole field.

The Bamford mining field is at Emu Creek in the valley of the Walsh, 97 miles inland from the port of Cairns. It is estimated that the total molybdenite production of the field up to 1915 was about 50 tons. Here again the ore is found in pipes of quartz and other siliceous rocks, lying near the margin of a granite intruded into porphyries. The pipes usually show a central cylinder of white quartz, surrounded by grey or blue quartz with a little mica, which shades off into greisen, and this, in its turn, passes into unaltered granite. The molybdenite often occurs as a sort of ring of isolated crystals around the margin of the white quartz.

Molybdenite is found sparingly on Bamford Hill, but more abundantly in claims both to the north and to the south of it. The most productive mine is Sunny Corner, which is said to be responsible for half the output of the field. In this mine are worked six principal pipes of milky white quartz lying in the granite near its contact with the overlying cap of porphyry; the pipes dip at 40° to 70° to the south and have been worked by inclined shafts down to 200 ft. They vary in diameter from less than 10 to 20 ft. The molybdenite and wolfram generally occur separately here, but bismuth is associated with both. A little molybdenite has also been marketed from the following, among other claims: Trafalgar, Violet, Northern United, Gillian and Bridge, Dog, Ballarat and Haymaker. This last lies on the crown of Bamford Hill at 2,100 ft. above sea-level [75].

At the Northern United mine, on Rocky Creek, there are some interesting pipes. The main shaft follows a pipe in quartz rock to a depth of 190 ft. In the sink (sump) a great vug was

broken into, which was found filled with abundant quartz crystals in an earthy crystallization mud, with molybdenite, galena and blende. The mud, stripped of the visible sulphides, contained the following percentages: Lead, 40·3; bismuth, *nil*; molybdic oxide (MO_3), 29·8; tungstic acid (WO_3), 9·4; gold, traces; silver, 62 dwt. per ton. The molybdenite tends to occur in bunches, with a preference for the under part of the pipe. In one case, where the quartz pipe was from 10 to 12 ft. long, and from 3 to 5 ft. wide, the whole of the molybdenite, which was of high grade, had collected within 6 in. of the underlying greisen.

At the Trafalgar Claim, on Rocky Creek, molybdenite occurs well disseminated to the extent of about 0·50% in greisen and biotite-granite, associated with galena and bismuthinite [75].

Molybdenite has been seen in many places near Khartoum, Northern Queensland. The country rock is hornblende-biotite-granite, with dykes and sills of fine-grained biotite-granite; connected with these are numerous quartz-veins and stringers often carrying molybdenite. The most important mine is the Kitchener, on which has been installed a flotation plant, and in which is worked a lode 4 to 12 ft. wide containing 3 to 4% molybdenite and up to 8% in places. Many other claims have also been located in this neighbourhood, including Perseverance, Riverview, General Joffre, Glossop, Singer, Asquith, General French, Ajax, Admiral Sturdee, Allies, Admiral Beatty, Jellicoe and others with similar topical names. All the deposits appear to be reefs and stringers of quartz; the Joffre lode seems to be the best, but the Homeward Bound lode has also yielded some good ore [76].

A few years ago a molybdenite deposit was discovered at Tyrconnell, near Wonbah station in the Mt. Perry district, which is likely to prove the most important one yet developed in Australia. The mineral occurs in a pipe of white quartz containing a certain amount of calcite in segregation in granite. The outer skin of the pipe consists of pegmatitic felspar which is surrounded by a ring of aplite. The pipe dips from 10° to 20°, and varies in diameter from 42 to 58 ft. It has been proved by a vertical shaft to a depth of 180 ft.

A face 16 ft. around the outer periphery is being worked, leaving a relatively poor central core 25 ft. in diameter. In the face of the central core some small masses of chalcopyrite, pyrite, galena and blende are seen in a calcite gangue. The molybdenite is disseminated in a patchy way in the pipe, the content appearing to range from 0·5 to 2·0% in large samples. One piece was found weighing 3 lb. The mine has a 10-stamp battery, and a Minerals Separation–De Bavay plant run by suction gas power [77] [78]. To the end of November the 1919 output amounted to 38 tons of concentrate of value £16,400 [79]. Operations were suspended in March 1920, on account of market conditions.

At other places near Mt. Perry the deposit takes the form of fissure veins, the country rock being a crushed granitic material more or less calcareous and close to aplite dykes.

At Boomarrie, near Cloncurry, molybdenite is found in a limestone close to schist country, no granite being visible in the vicinity, and at the Magnet, 35 miles N.N.W. of Cloncurry, the rocks are biotite-schist and granite, the molybdenite being in an irregular quartz lode in the schist with chalcopyrite [80/p. 463].

South Australia

Molybdenite is widely, though sparingly, distributed in the well-known Moonta and Wallaroo copper regions of South Australia, but is chiefly confined to the lodes of the eastern and central belts of fracturing. The greatest development appears to have been in the Yelta lode, where it occurs in sporadic bunches in fairly massive "books," which show in some instances rudely crystallographic outlines. From 2 to 3 tons are stated to have been picked from the Yelta ore in a year. At Moonta molybdenum near the surface is sometimes covered with the ochre, molybdite. Molybdenite is also found in small amounts in the Wallaroo lodes [81]. From 1917 to 1919 inclusive the output only amounted to 26½ cwt. There was no production in 1920.

Victoria

At Wangrabelle, Gippsland, Victoria, a quartz lode in granite, from 10 to 18 in. in thickness, carries much molybdenite, pyrite,

white mica and molybdite. In 1914 it had been worked for a length of 50 ft. at a depth of 50 ft. [82].

At Everton, in the Beechworth district, molybdenite occurs in the granite bosses where the rock is intersected by irregular veins and secretions of quartz. The ore is associated with finely disseminated pyrite, and a little molybdite occurs near the surface. In the Standard mine the ore-body is dome-shaped, but does not extend to the surface. The property is well equipped and includes a Minerals Separation flotation plant [83].

The mill was completed in 1920; 250 tons of ore gave approximately 8 tons 2 cwt. of concentrate assaying 85% molybdenite. The present capacity of the mill is 21 cwt. per hour, which could be increased by installing an additional grinding pan [84].

Productions of molybdenum (estimated metal contents of ores) in Victoria follow:

	1918.	1919.	1920.
Metric tons . . .	3	43	23

[11/1920]

Western Australia

Molybdenum ores have been reported, and to a small extent worked, at several localities in Western Australia, but the amount of development carried out is small, owing to poor demand for the ores, and to transport and labour difficulties. Production began in 1917; the total production to the end of 1920 was 26½ tons of molybdenite ore, valued at £360 [85].

In this State molybdenite occurs in quartz veins in granite and in pegmatite dykes. Some development work has been done on the Mt. Mulgine deposit near Warriedar, on the Yalgoo goldfield. This deposit, which lies on the west slope of Mt. Mulgine, a granite hill rising some 300 ft. above the general level of the country, has been the chief, if not the only source of supply. The granite of the hill is ribbed with pegmatite dykes and quartz veins, which carry the ore, and a sample taken in 1915 assayed 6·2% molybdenite. The molybdenite is found in crusts of rosettes and in bunches along cracks and in flakes up to ½ in. across: it is sometimes altered to molybdite. There seems to be a fair tonnage of ore up to 1% grade. Molyb-

denite is also found in quartz at Gullewa, some distance to the north.

At a place called "Thomas's Show," 17 miles N.E. of Leonora, small pegmatite dykes and quartz veins in a boss of red granite carry flakes of molybdenite up to ½ in. in diameter, and at Callie Soak in the Murchison mining field a deposit of scheelite and wolfram, worked as a source of tungsten ore, carries molybdenite in addition. A sample yielded 9% tungstic oxide and 2·02% molybdenite.

At Coolgardie a few small specimens of molybdenite have been found embedded in amphibolite. At Bulla Bulling and also at The Terrace in the Mount Margaret Goldfield it is moderately plentiful in quartz veins in granite. At Southern Cross there are small flakes and crystals in quartz, and at Swan View, in the Darling Range, 14 miles from Perth, it is fairly plentiful in grey granite. Small flakes in quartz have also been recorded from Wagin, from Ravensthorpe, from Clackline and from Blackboy Hill [86] [87].

Tasmania

Molybdenite has been observed at a good many localities in various parts of Tasmania, but none of the deposits seems to be of much importance, and the production has hitherto been a small one. Molybdenite occurs as an original constituent of a Devonian biotite-granite on the west side of Mt. Stronach near Scottsdale, in specks and in crystals up to ½ in. across, sometimes intergrown with felspar. A little work has been done on the pegmatites of this area, but the mineral is not abundant, the total content being only about 0·1%; they are therefore unpayable. One or two impregnations along fractures and a seam from 1 to 2 in. thick might be worth working.

In an area lying in the hinterland of the Scamander district, some 6 miles from the coast, wolfram-molybdenite lodes are found in pre-Silurian slates and micaceous quartzites in the neighbourhood of Devonian granite, within an area of about 4 miles from north to south by 1 mile from east to west. The lodes, which average 1½ to 2 ft. in width, consist of quartz with wolfram, arsenopyrite and molybdenite of appreciable

and persistent content; some mineral is also found in the adjoining country rock [88/Pt. I.] [89].

The district of Moina is in Northern Tasmania, about 22½ miles south of Sheffield, Co. Devon. The Squib mine is 1½ miles east of Moina. Its principal ore mineral, wolfram, is associated with molybdenite, bismuthinite and cassiterite. Accessory minerals are gold, pyrite, chalcopyrite, blende and arsenopyrite. The gangue is white opaque quartz with which are associated topaz, fluorspar, beryl, monazite and gilbertite (secondary). The central part of the vein is occupied almost wholly by white opaque quartz, showing blebs of wolfram, molybdenite, pyrite and chalcopyrite, and also having blende distributed sparsely through it. The molybdenite was formed later than the cassiterite, and both earlier and later than the wolfram. The veins traverse both granite and quartzite, the richest appearing to be the quartz veins in quartzite. At this mine the molybdenite is more common in the hard quartzite, and pyrite and mica are abundant both in the lode and wall-rock. One open working shows a body of ore, 20 ft. wide, consisting of greisen traversed by 15 veinlets of quartz, from 1 to 5 in. thick, carrying wolfram, bismuthinite, bismutite and molybdenite. The ore is concentrated by jigs and brought up to 25% molybdenite and is sold for further treatment. The mine has been worked on a small scale since 1911.

The S. and M. Syndicate's mine is close to the Squib. There are several E.–W. quartz lodes striking across the country, which is quartzite to the east and garnet rock to the west. Cassiterite, wolfram and bismuthinite are the dominant minerals, molybdenite being present only in subordinate amounts, except in some parts of the No. 4 lode, where it is in close association with wolfram.

In the No. 2 workings of the Premier mine the lode is a fracture-filling, from 4 to 6 in. wide, in pegmatite granite. Wolfram, bismuthinite and molybdenite occur coarsely crystallized and highly developed in a quartz gangue. Molybdenite flakes 1 in. in diameter are common in the lode and adjacent granite, and here the granite contains a little biotite, whilst pyrite and green fluorspar are accessory.

In the Hidden Treasure mine, 17 miles south of Sheffield,

pegmatite occurs in the form of irregular dykes of very varied width, and consists of quartz, felspar and pinite. This pegmatite carries blebs and pockets of wolfram, molybdenite and bismuthinite, and contains a number of quartzose veins, from 3 to 8 in. in thickness, rich in those minerals. The associated minerals are pyrite, chalcopyrite, fluorspar, topaz and muscovite. One quartz vein contains 1% tungstic oxide (WO_3) and 0·15% molybdenum. A sample from another vein yielded 5·9% tungstic oxide and 8·05% molybdenum.

A large quantity of detrital material exists derived from the decomposition of the pegmatite in the mine. According to A. McIntosh Reid, from whose memoirs on the region the above notes are taken, the detrital matter contains payable quantities of wolfram and molybdenite [90].

Twelvetrees points out the remarkable absence of tourmaline throughout the region [91]. Reid says it is very rare, but that near the granite contact it occurs sparingly in the form of thin laths in porphyroid rock [90/p. 50].

On the eastern side of the River Forth are lodes in granite up to 12 or 15 in. wide, average samples of which are said to have returned 2% each of wolfram and molybdenite. These lodes are worth exploring [88/Pt. II, p. 11].

Small quantities of molybdenite are found in the scheelite deposits of King Island, Bass Strait, the average being only 0·024% molybdenum or 0·04 molybdenite; there are occasional rich patches. The occurrence is in a garnet rock of the skarn type, consisting of pink garnet and green pyroxene, with quartz, epidote, calcite and actinolite. Waterhouse regards the deposit as a replacement of calcareous beds by scheelite and molybdenite, introduced by the granite magma [92].

In the South Heemskirk tin-field molybdenite occurs associated with cassiterite in veins, and also as impregnations in granite [93].

New Zealand

Molybdenite has been recorded on Ohio Creek, in the Thames Goldfield of New Zealand, in a 12-in. vein of quartz and pyrite, also in small veins branching from the main leader [94]. At a place called Fourteen-mile Creek, near Greymouth, on the

lower slopes of the Paparoa range, and about 1,000 ft. above the sea, several quartz veins in Maitai slates contain molybdenite. The veins are nearly vertical and from 4 to 9 in. wide with flat leaders 1 to 2 in. thick. The molybdenite occurs in the veins as platy masses of the size of small peas, and in veinlets, with pyrite and talc. An assay of a loose piece picked up in a creek gave 15·3% molybdenite. One vein contains 15 dwt. of gold per ton [95].

In the Mt. Radiant district, Westport Division, in the N.W. corner of the South Island, metalliferous veins occur in granite, forming a zone 1¼ miles wide along the western edge of the Mt. Radiant block: they are best developed from the confluence of Fugel Creek with the Johnson River to a little beyond Mt. Scarlett, a length of 4 miles. The veins, which are vertical or dip N.N.E. or N.N.W. and vary from a few inches to 20 ft. in width, are somewhat lenticular in character and seem to pinch out rapidly. Some are nearly pure quartz veins, while others are pegmatitic in character with felspar and mica: the walls are often greisen-like and the whole sometimes approaches a stockwork. They contain chalcopyrite, often with secondary bornite, chalcocite and covellite, and, generally, molybdenite, as stringers of ¼ or ½ in. wide or as coatings on slickensided joint-faces, and occasionally finely distributed throughout the gangue. There are also present a little gold and silver, associated with pyrite, with sometimes lead and zinc sulphides. The best occurrence is the Mt. Radiant reef, where molybdenite is common in veins, spots and bunches. A picked sample from the drive gave 6·2% molybdenite, but there is usually less than 2% in a large sample.

The Mt. Radiant vein-system has a total width of about 66 ft. and consists of a series of parallel veins up to 3 ft. wide, with small irregular ramifying stringers. The veins seem to pass into typical pegmatite in muscovite-biotite-granite.

The New Anaconda reef in Specimen Creek, ¾ mile above its junction with the Little Wanganui River, at 1,850 ft. above sea-level, with a maximum width of 19 ft., is traceable for about 12½ chains. It has a well-defined foot-wall, but the hanging-wall passes into veinlets and stringers of quartz and pegmatite in silicified greisen-like country rock. This reef

contains a very small amount of molybdenite, copper being the dominant metal. Assays from a large number of outcrops in this division show that molybdenum is almost invariably present, though usually in amount under 0·1%; the highest record is 6·76% molybdenite from the main ore-shoot of the New Anaconda reef, but this is certainly not representative. Crabbe's reef, Swag Saddle, the Fugel Creek reef and others usually assay under 0·3% [96].

Molybdenite has also been recorded at Richmond Hill, near Parapara; at Bravo Island, near Stewart Island; and near Dusky Sound [36].

CHAPTER III

SOURCES OF SUPPLY OF MOLYBDENUM ORES (*Continued*)

(*b*) FOREIGN COUNTRIES

EUROPE

Finland

According to J. J. Sederholm [97] molybdenite occasionally occurs in granite veins in Finland, usually in small quantities. Deposits of molybdenum ores, occurring in the vicinity of the railway line from Joënsuu to Nurmes, are now to be exploited. Ore was mined in 1910 at Mätäsvaara, north of Joënsuu, but the mine was subseqently abandoned as of little value [98]. Molybdenite occurs in small quantities at the Omeljanoff mine at Pitkäranta, as small tabular crystals in pegmatite or in metamorphosed limestone (skarn rock).

France

In France molybdenite is found in pegmatites at Miséri, near Nantes, with biotite, muscovite, beryl, chalcopyrite and arsenic ores; also in veins with tinstone and wolfram in Haute Vienne, and with wolfram in the well-known deposits of St. Léonard, near Limoges. It occurs in mineral veins in several localities, such as Chessy in the Central Plateau, and in the red granite of the Glacier de la Meije, near La Grave, in Dauphiné. It is also known to exist to a considerable extent in the "protogine" or gneiss of the Mont Blanc massif, especially around the Mer de Glace.

According to F. J. Stephens molybdenum ores of good quality occur in the Vosges, both as "selvages" and as a constituent of true lodes of argentiferous copper, which were worked very successfully over 300 years ago for their silver and copper contents. Thousands of tons on the old dumps contain molyb-

denite ores scattered in quantity through them [62/p. 199]. In Brittany wolfram, cassiterite, molybdenite and other minerals occur in a network of veins (stockwork) in the tourmaline-granites near their contact with mica-schists [99].

So far as is known there is no production of molybdenite on a commercial scale in France.

Germany

Molybdenum ores have been mined in Germany in recent years, but no figures are available as to production, which is probably very small. Molybdenite occurs as a rare constituent of the innumerable small tin-bearing veins that traverse a granite dome in contact with mica-schist near Geyer, Erzgebirge, and in the tin-bearing seams or bands ("Risse") that traverse mica-schist at the Sauberge, near Ehrenfriedersdorf [100]. At Sadisdorf, Saxony, molybdenite occurs in fair quantity with cassiterite, wolfram and copper ores in a stockwork in muscovite-gneiss [101].

Italy

Molybdenite is only found at a few places in Italy; it occurs at Traversella, in Piedmont, in grains in syenite; at Drusacco, associated with chalcopyrite; at Quittengo, in the province of Novara, in quartz veins with pyrite; at Bolladore, near Sondalo in the province of Sondrio, in minute scales and plates in granite; and at Villaputzu, in the province of Cagliari in Sardinia. It has also been recorded at Monte Somma in association with galena. There are also minute quantities in other localities, none of which seems to be of any importance [102]. There was a very small production of molybdenite in Italy in 1917.

Norway

For many years past Norway has been recognized as one of the chief sources of molybdenum ore, and the special conditions of the war period undoubtedly gave a considerable impetus to production in that country, the bulk of the ore probably finding its way to the German market. In 1916 and 1917 the exports

from Norway to Germany are given as 53 tons and 133 tons, respectively, of concentrate varying from 70 to 90% molybdenite. The price was excessively high. As early as 1915 German agents were reported to be offering £2,000 per ton for 80% concentrate, and quotations afterwards became still higher.

Molybdenite is known to be widely distributed as an accessory constituent of igneous rocks in Norway, especially in pegmatites. From Brögger's description [103] of the pegmatites of South-Western Norway, it appears to be common in the dykes of the Laurvik and Frederiksvärn districts, and in the Langesundfjord, especially on the island of Låven at Laurvik, at Lövö and at Klokkerholmen; it is associated with chalcopyrite, löllingite ($FeAs_2$), blende and galena, and with a vast number of minerals containing rare metals, especially thorium, cerium and zirconium, as well as compounds of uranium. It is apparently not present in commercial quantities. It has also been recorded by Goldschmidt in metamorphosed calcareous rocks in the Kristiania district, especially at syenite contacts in the type of rock known as skarn, with garnet, wollastonite, scapolite, axinite, fluorspar and copper, zinc, lead and bismuth minerals [104]. This may be compared with the Canadian and Tasmanian occurrences mentioned elsewhere.

However, practically the whole of the Norwegian production comes from a few mines in the south, in the districts of Knaben, Moi, Siredalen, Mandal, Telemarken, Drammen and Haugesund.

According to Otto Falkenberg, the ore-bearing zone is about 12 miles long from north to south, and upwards of half a mile wide. It is intersected by several dolerite dykes coursing approximately E.–W. and which are up to 16 ft. in width. They do not appear to have any influence on the occurrence of molybdenite [105].

Over most of this area the country rock is granite or gneiss; the two noted exceptions are the Dalen and Gursli mines, described later. The occurrences are of three types, namely, quartz lodes, mineralized fissures in granite, and disseminations in granite.

The Knaben district, one of the most important producers, is east of Stavanger and N.E. of Flekkefjord. Here there are

about seven mines in operation and some promising prospects. Knaben No. 1 mine, owned by a British company, is the most important. Three lodes running N.N.E.–S.S.W. and underlying flatly to the east are worked by three levels, the lowest being only 80 ft. below adit level. The lodes are mineralized over a width of about 30 ft. and are very rich in parts, but little ore appears to exist below the 80 ft. level. Masses of solid molybdenite up to 4 cwt. have been found. The ore is crushed and treated by the Elmore process, the machinery being worked by a 150 h.p. hydro-electric plant. The output in 1917 averaged about 5 tons of concentrate per month, containing 75 to 90% molybdenite.

Knaben No. 2, belonging to the same company, is about 2 miles south of No. 1. In it is worked a large dissemination in granitic gneiss, several hundred feet long and in places over 100 ft. wide. The treatment plant is of the same type as that at No. 1.

The Kvina mine is about a mile north of Knaben No. 1. In it is worked a very flat-lying quartz lode with hanging-wall of granite and foot-wall of brecciated quartz and pegmatite. The ore is low-grade; perhaps of 0·3% content, but the plant is effective and during the war the company turned out 3 or 4 tons of 75% concentrate per month.

Ornehommen is an important mine worked by a Norwegian company; its ore-body is a somewhat erratic mineralized fissure in granite, and the machinery is worked by hydro-electric power.

Baenkehei is a small mine adjoining Knaben No. 2 which was just beginning to produce in 1917, and Lilleknaben, belonging to an English company, was at the same time prospecting a mineralized fissure and erecting a Minerals Separation flotation plant.

The Dalen mine in Telemarken started producing in 1916, working a flat quartz vein in a siliceous slate, varying in width up to 3 ft. and traceable for some 200 yds.; this appears to be in connexion with a granite outcrop about a mile away, which also contains molybdenite. This mine has been a large producer, yielding high-grade hand-picked ore, besides concentrate. Unusually large flakes of molybdenite from this mine are

reported to fetch a special price for use as rectifiers in wireless telegraphy. The Haugholmen and Bandaksli mines in the same neighbourhood also yield small amounts of hand-picked ore.

The Orsdal mine, in Siredalen, was worked for some years by the British Molybdenum Co., Ltd.; after lying idle for a time it has been taken over by a Norwegian company. It yields a small amount of wolfram as well as molybdenite. The Bykle mine in Mandal is very remote, and apparently has only a low-grade ore.

In the Gursli mine, near Moi on the Flekkefjord Railway, are worked two parallel fissures outcropping on the face of a cliff. The country rock is norite, and the lodes contain sufficient mica and copper to make concentration difficult. There is also a low-grade dissemination of molybdenite in a mass of norite, also carrying copper.

Molybdenite has also been reported, and in some cases worked on a small scale, in the following localities: Syversvolden; Ostvaago; Smölen; Langvaten and Tjaardalskampen, the last four being in the northern part of Norway. Their production appears to be small [106].

In the Flekkefjord veins, pyrite, chalcopyrite and pyrrhotite occur in varied quantities; besides quartz, other gangue minerals are felspar, mica and hornblende. Molybdite is met with rarely [105]. According to Falkenberg, besides molybdenite, there are found in the Mineralskapets mine, chalcopyrite, pyrite, quartz, felspar, biotite and muscovite. In some deposits fluorspar, tourmaline, calcite, augite and epidote are occasionally found. At one deposit there are magnetite and garnet.

Falkenberg estimates the total production of Norway up to the end of 1919 at 800 tons of pure molybdenite, and states that the country could produce 150 to 200 tons per annum [107]. The average yearly production from 1902 to 1913 was 23½ tons of 90 to 95% molybdenite [108]. There was no production in 1920 and 1921, but productions of molybdenite since 1914 are as follow:

	1914.	1915.	1916.	1917.	1918.
Metric tons . . .	83	97	137	248	228

[11/1920]

Russia

Molybdenite is known to exist in various parts of Russia. Near the Miskhansky Copper Smelting Works, 6 miles N.E. of Bash Abaran, Erivan government in the Caucasus, syenite is intersected by veins of reddish-brown quartz with copper ores and molybdenite. It is also found in the Zanguezur district in the Elizavetpol government, not far from the Agaraksky mines, and in the syenite of the Ilmensky Hills, on the River Cherelipanky on the eastern slope of the Urals. Deposits of molybdenite are found in the Kirghiz Steppes and in the Transbaikal province of South-West Asia; none of these was worked up to 1912, but the Russian resources were being explored by German mining engineers before the war. It appears probable that the Siberian deposits at any rate are of sufficient importance to be workable [109].

Spain

In Spain molybdenite has been encountered in several localities, chiefly as small scattered hexagonal crystals in quartz veins. It is recorded from both flanks of the Sierra de Guadarrama, at Villacastin, at Navacerrada and at Hoyo de Manzanares; apparently the most promising occurrence is at the Torrelodones tunnel, between Madrid and the Escorial, where it is found in granite with chlorite in crystals up to ½ in. in diameter. It is also known at Cuevas de Salabe, in Asturias, in kersantite, in shapeless lumps, often covered with a reddish ochre, and with bismuth minerals in gneiss at Espinabel, in Gerona. Wulfenite occurs at the Socorro mine in Linares in tabular crystals of a yellowish colour; also in the veins of the Madroñal and San Roque, as well as in the Sierra de Mijas (Málaga). Wulfenite is found associated with galena in a Triassic limestone in the Sierra Nevada, 12 miles north of Granada; this deposit has been exploited by the Société Procédés Paul Girod of Lyon. Wulfenite also occurs in considerable quantity at several places east and south of Granada, associated with galena. For many years this ore was thrown on the dumps of the lead mines, but it has recently been collected and exported in some quantity. The mineral here occurs at three distinct geological horizons, in each case

in a limestone, of which the oldest is pre-Cambrian and the latest Triassic; the age of the middle occurrence is unknown. The wulfenite accompanies galena and forms replacement deposits at particular horizons in the limestone, the ore-bodies closely following the bedding. The chief localities are at Vélez de Benaudalla and Güéjar Sierra in the Triassic limestone; in the mines of San Antonio de Padua and Nuestra Señora del Rosario, also in the Trias near Albuñuelas; and in the Quentar group in the Umbria del Madroñal 9 miles east of Granada. In the province of Almería wulfenite deposits also exist in Triassic limestone 4 miles from Ribera de Oria [110].

The total output of Spanish molybdenum concentrate in 1915 was 59·9 tons and in 1916, 147·2 tons, but the molybdenum content is unknown [111 to 113].

Sweden

According to F. J. Stephens molybdenite occurs in Sweden as in Norway, and also in a molybdenite-schist not far from Nörrköping, probably a replacement product. It is also found freely in an altered serpentinous rock, both in veins of similar material and in the serpentine itself [62/p. 199].

In the Island of Ekholmen, in the archipelago of Vestervik, molybdenite occurs in hornblende-gneiss and mica-schist. There are 7 veins from 6 to 18 in. in thickness. The vein filling consists of molybdenite, chalcopyrite, quartz and felspar and a little molybdite. The veins have yielded lumps of pure molybdenite up to 5 lb. in weight [114/p. 337]. Molybdenite production in Sweden began in 1914 (*see* table, p. 12).

Yugo-Slavia

The occurrence of wulfenite in the lead ores of Carinthia (Slovenia) is noted by T. C. F. Hall [115].

The Misitsa (or Meiss) lead mines are 11 miles S.E. of Pliberg (or Windisch-Bleiberg) in Northern Slovenia, formerly part of Austria. The formation consists of Triassic limestones and dolomites much folded and cut up by large faults. Galena and wulfenite are the principal ores and occur in veins in zones

of local brecciation. The ores cease when slate comes in on the hanging-wall. The decomposition product, *ilsemannite* ($MoO_2.4MoO_3$) sometimes occurs in the area, embedded in barytes [116].

From 1914 to 1917 inclusive, 97 metric tons of wulfenite ore were mined by the Austrians. There was no production in 1918 [117].

ASIA

China

Molybdenite in small amount is to be found in the wolfram-bismuth quartz veins in granite at the Kuku mines, east of Shiuchow, Kwang-tung [118/p. 16]. Productions of molybdenite in China for the years 1916-18 are given in the table on p. 12.

Japan

Molybdenum ores have been found in the following five prefectures in Japan: Gifu, Toyania, Niigata, Totori and Hyogo. No information is available with respect to these occurrences, although there has been some production, particularly during the war period [11/1917, p. 466].

Siam

Molybdenum ores have been reported in the Siamese-Malay States, and at Chantabun on the east coast of the mainland of Siam. There has been no production [11/1917, p. 467].

NORTH AMERICA

Mexico

Ores of molybdenum have been found in at least twelve states of Mexico, but it is rare to find them in economic quantities.

The San José copper deposits in the State of Tamaulipas occur in a contact-zone of diorite-porphyry and limestone. The latter rock is altered to wollastonite, diopside and garnet (mainly grossularite and andradite), associated with vesuvian-

ite, and occasionally with molybdenite [119/p. 630]. Molybdenite is said to be quite abundant in some of the workings of the copper mines, e.g. the Santa Elena adit has yielded from 0·05 to 1·0% molybdenite for some distance. In the San Domingo shaft it occurs in a garnet-zone with vesuvianite [120]. Molybdenite is said to occur in association with granite in the mountains within 20 miles of Nacosari, Sonora. The molybdenum content ranges from 1 to 2%, and some stringers are much richer. In the district of Sahuaripa in the same state, some high-grade deposits of molybdenite and scheelite were being developed in 1917, and some shipments of ore were made [11/1917, p. 461]. In El Porvenir district scheelite occurs with quartz, felspar, molybdenite and copper minerals in pegmatite [121]. Molybdenite occurs in veins in granite near Temascaltepec, State of Mexico. Wulfenite, containing more than 25% molybdic oxide (MoO_3), is abundant with lead ores in the Cuchillo Parado mine in Eastern Chihuahua: some shipments have been made [11/1909, p. 531]. Wulfenite has been found in at least six states. Molybdite, no doubt associated with molybdenite, occurs in several districts in the State of Hidalgo [119/p. 486].

Productions of molybdenum concentrate in Mexico were:

	1918.	1919.	1920.
Kilograms . . .	27,371	1,767	648

UNITED STATES

About the year 1903 a few tons of molybdenite concentrate were produced from a mine at Crown Point, Chelan Co., Washington State; this occurrence is described later (*see* p. 74).

A considerable amount of ore was also obtained from the tailing of a cyanide plant at Mammoth, Arizona. From 1903 to 1914 a few very small lots of concentrate from Crown Point are the only recorded output, but in 1915 production began in earnest, when the Primos Chemical Co., of Primos, Pennsylvania, purchased a molybdenite prospect on Red Mt., near Empire, Colorado, and rapidly developed the property. In 1915 the production amounted to about 82½ metric tons of metal, and in 1916 to 94 tons, thus equalling the average production of Canada, Norway or Queensland, and bringing the

United States into the first rank. Since then the industry developed rapidly, and the output of metal for 1918 was 391 tons. There was only one producer in 1920—the Molybdenum Corporation of America, operating at Questa, New Mexico. There was no production in 1921 owing to lack of market.

Up to 1917 the greater part of the United States production of molybdenum ores came from the wulfenite deposits of Arizona, and most of this from the Mammoth and Collins mines, at Schultz, Pinal Co., about 48 miles north of Tucson. This is the only state in which wulfenite appears to be of importance as an ore, although it has been recorded from Utah, Nevada, California and New Mexico. It occurs chiefly in the oxidized zone of lead ores and appears to be of secondary origin. Although occurrences of molybdenite have been recorded in 26 states and of wulfenite in 11 states, yet the majority of these are of little importance [122/p. 86]. It is obviously impossible to describe or even to catalogue all the known occurrences, and only a few will be selected as typical of the rest.

Alaska

At Shakan, Prince of Wales Island, Ketchikan district of Alaska, at an altitude of 600 ft., there is a fissure vein of quartz, striking nearly E.–W. in diorite near the contact with tufaceous sediments, which carries molybdenite, chalcopyrite and pyrite [123/p. 89]. According to a report, written by F. W. Bradley, the vein outcrops for 500 ft., and a gallery has been driven 320 ft. on the vein. The average width of surface and underground exposures is 5·85 ft., and the assay 1·58% molybdenite, indicate 100,000 tons of ore, of which 6,270 are positively blocked out with an average of 2·28% molybdenite. The property is owned by the Alaska Treadwell Co. [11/1920, p. 465].

The Arnold gold-bearing lode at Willow Creek, near Marshall, contains, besides free gold, calcite, pyrite, galena and molybdenite, and the concentrate from panning includes small amounts of wulfenite and anglesite [124]. Vein quartz, carrying a considerable amount of molybdenite, has been found in at least two localities in the Archangel Creek Basin, Willow Creek district [123/p. 186].

Near the extreme head of Healy River, 160 miles S.E. of Fairbanks by trail, at an altitude of 6,000 to 6,500 ft., there is a deposit described as a hard white quartz fissure vein in granite, striking E.–W. and dipping N., which carries bunches of molybdenite scattered sparingly, but rather evenly, throughout [123/p. 329]. In the Columbia mine, Fairbanks district, there is an iron-stained lode 4 ft. in thickness, striking N. 50° E. and dipping 45° N.W., composed of silicates, which have replaced limestone beds, and cut by quartz stringers. Both the silicates and the later quartz stringers are rich in scheelite and contain a little molybdenite [123/p. 326].

At Cassiterite Creek, Seward Peninsula, molybdenite occurs in cassiterite-wolfram veins and stringers in quartz-porphyry intrusive in limestone [118/p. 17].

Molybdenite occurs with gold, chalcopyrite, galena, blende, pyrrhotite and pyrite at the Treadwell mine, which is now flooded. The occurrence is similar to that in the Southern Appalachians, where molybdenite is found in gold-quartz veins, with arsenopyrite, pyrrhotite and tourmaline, and sometimes galena, blende and chalcopyrite.

Arizona

In 1917 the State of Arizona was by far the largest producer, having apparently shipped nearly the whole of the United States output of ore, equivalent to about 170 short tons of metal: the value is stated at nearly half a million dollars. Most of the ore was wulfenite obtained from the Mammoth mine at Schultz, some 40 miles north of Tucson, and especially from the old dumps of that mine, which was at one time worked exclusively for gold. During the last few years wulfenite ore has been raised by the Mammoth Development Co. from this mine and from the adjacent Collins claim, which is worked through the same shaft; the mill is near the San Pedro River, 3 miles east of Schultz, and is fitted for flotation.

This mine is situated on two roughly parallel veins, 600 or 700 ft. apart, striking in a general N.W.–S.E. direction and dipping 45° to 70° S.W. Their width is very varied, that of the Mammoth vein being from a few inches up to 60 ft., and

averaging 14 ft. for a length of 750 ft. The Collins vein has an average width of about 12 ft. The filling of the veins is mainly brecciated rhyolite and granite, highly altered and silicified. The ore contains wulfenite, vanadinite, descloizite, cerussite, anglesite, azurite, malachite and chrysocolla, with, here and there, a little unaltered galena. A few hundred feet to the west the old Mohawk gold mine also contains the same rich wulfenite ore with rather more vanadinite. But most of the production of molybdenum in this locality came from the old dumps, which have recently been again worked over by the Arizona Rare Metals Co. The tailing from the cyanide mill was spread over a considerable area and was estimated in 1916 to contain 200,000 to 250,000 tons of material with 1 to 2% of wulfenite [122/pp. 46, 115] [125/1916, p. 777]. These dumps are now exhausted.

In the Total Wreck mine, 9 miles south of Pantano, wulfenite and silver-lead ore have been also worked, the wulfenite being shipped to the Molybdenum Products Co., at Tucson, where it was converted into a sodium molybdate slag, the final product being eventually sold to the Atlantic Metal and Alloys Co. at Boonton, New Jersey, for smelting to ferro-molybdenum.

The second largest molybdenum field in Arizona is along Copper Canyon, which drains the east side of the Hualpai Mts., about 25 miles S.E. of Yucca. From the head of Copper Creek a series of claims extend to its junction with Deluge Wash, the workings being in quartz veins in granite. The veins originally contained pyrite, chalcopyrite, blende and galena, and on a subsequent brecciation molybdenite was introduced. The only producing company in 1918 was the Leviathan Mines Co. in Copper Canyon, about a mile from Deluge Wash. The ore-body is 20 ft. wide in places, but averages about 7 ft. It carries about 1% molybdenite with nearly as much copper. The ore is concentrated to 20 or 30% molybdenite and 18 to 25% copper by oil flotation, but work is much hampered by want of water. Numerous other claims have been prospected and a certain amount of development has been carried out [126].

There are many other molybdenite deposits in the Hualpai Mts. Claims have been located in two canyons on the west side

of the range, 18 miles N.E. of Yucca, and in the N.E. part of the range, 20 miles S.E. from Kingman, is a group of claims on Bottleneck Wash, on a stockwork of small veins in granite, carrying molybdenite with pyrite and a little lead and zinc. At water-level some molybdenite has accumulated —apparently a case of secondary enrichment. The property is owned by the Standard Minerals Co. Some of the veins have been encountered at a depth of 400 ft., and a 40-ton mill has been erected [11/1920, p. 463]. About a mile south of Bottleneck Wash, on the ground of the Telluride Chief Co., a 30-ft. zone assayed 1 % molybdenite. A shaft has been sunk 200 ft. and the workings cut a mass of quartz-felspar veins 2 or 3 in. thick with molybdenite in fine scales. A small mill has been erected here.

At Soap Wash, 4 miles S.W. of Bottleneck Wash, the Jackman Claims are on a series of quartz veins in coarse granite: the veins carry molybdenite, pyrite, chalcopyrite and blende, and, here and there, a little wolfram. A few tons of ore carrying 3·5 % molybdenite are said to have been picked out, but most of the veins are rather poor.

The Helvetia Copper Co., at Helvetia, Pima Co., in the Santa Rita Mts. area, has produced a considerable quantity of high-grade molybdenite ore as a by-product in copper-mining. The Leader mine, worked by this company, lies in altered Palæozoic limestone with garnet and secondary quartz due to silicification, close to its contact with granite: the lode which is 6 or 7 ft. thick lies mostly in the quartz, and large samples have assayed up to 6·5 % molybdenite. In the Ridley mine of the same company is worked a tabular quartz vein with galena, blende, chalcopyrite and molybdenite, associated with pre-Cambrian granite. Other occurrences of similar type have been noted at Madera Canyon, Providencia Canyon, Buena Vista, Duquesne and San Antonio Canyon in the same district [127] [128].

At the old Yuma mine, Pima Co., the country rock is a badly shattered and highly altered acid eruptive, and carries wulfenite (2 to 3 %), vanadinite and cerussite. The wulfenite occurs in seams and cracks throughout the ore in thick tabular crystals, and as minute specks and irregular masses in the cavities of

the rather porous vein material [122/p. 48]. The deposit has been mined to a depth of 300 ft. on the dip (45° S.E.).

California

According to Calkins the country near Ramona, San Diego, California, is biotite-granite cut by aplite dykes. In one of the latter, which is 50 to 200 ft. in width and traceable for 1,500 ft., molybdenite is very unevenly distributed in the rock, and is, in places, altered to molybdite. Pegmatitic bodies, with abundant quartz, contain the molybdenite [129].

Horton describes the deposit as a dyke of granite in which molybdenite occurs in crystal aggregates and irregularly shaped masses of radial structure (mostly $\frac{1}{8}$ to 1 in. in diameter) and associated with a little pyrite. He is of opinion that the ore averages perhaps 0·25 to 0·50% molybdenite. The deposit has been tested by open cuts, but is probably too poor to mine [122/p. 60].

In 1917 several hundred tons of molybdenite rock were obtained from Boulder Creek, near Gibson Spur, in Shasta Co. There are other occurrences near Bridgeport, Mono Co., and 4 miles from Sweetwater, Nevada Co., just inside the Californian boundary, where some ore was mined and shipped carrying 3% molybdenite. In Tulare Co. ore was found in granite on the Kaweah River at a high elevation, and the Imperial Lode Mining and Reduction Co. extensively worked a wulfenite-silver property 6 or 7 miles S.W. of Lavic, San Bernardino Co., but no production of wulfenite was made [125/1917, p. 913].

Colorado

In 1918 the most important molybdenite mine in the United States was that on Bartlett Mt., near Climax, Summit Co., Colorado, belonging to the Climax Molybdenum Co. The mine is situated at an elevation of 11,300 ft. on the Continental Divide, and the climatic conditions are very severe. The ore-body consists of a highly siliceous phase of an intrusion of granite into gneiss: this irregular mass shades off on all sides

into normal granite. The more siliceous rock consists mainly of quartz, with subsidiary felspar. The mineralized zone is traversed by an intricate network of quartz stringers; the molybdenite is very fine in grain and occurs mostly as a dissemination in the quartz, to which it imparts a bluish colour. No other minerals are present, except a little pyrite and a considerable amount of molybdite to a depth of 500 ft. from the surface. Development started in July 1917, and the first shipment of concentrate took place in February 1918. About 6,000,000 tons of 1% molybdenite ore[1] have been blocked out, starting from an old 900 ft. tunnel formerly driven on a supposed gold vein, and another tunnel has been started 200 ft. below. The mine is to be worked by means of parallel stopes, 800 ft. long by 25 ft. wide, with pillars of the same size. The stopes will be afterwards carried as shrinkage stopes to the surface and the pillars ultimately broken down into the stopes. The mill now has a capacity of 1,000 tons of ore per day and is worked by electric power transmitted at 13,000 volts from the generating station of the Colorado Power Co. [125/1918, p. 796] [130].

The Molybdenum Products Corporation also has a claim on the same ore-body, but this is not now worked, while the Pingrey Mines and Ore Reduction Co. have located claims on Ceresco Mt., on what is probably an extension of the same mass. Both companies are in a position to produce on a large scale should a sufficient demand arise, and it is estimated that this locality contains 100,000 tons of molybdenum metal, the deposit being probably the largest known.

The Urad molybdenite mine, Clear Creek Co., recently acquired by the Vanadium Corporation of America, consists of a group of nine claims on Red Mt., at an altitude of 10,000 to 12,000 ft., and about 14 miles from Empire station on the Colorado and Southern Railroad. There are three veins of low-grade ore, consisting of brecciated porphyry with molybdenite in flakes, or more commonly in a finely granular form, associated with pyrite, and occasionally in small veinlets and stringers in the porphyry. The ore averages about 2%

1 The above estimate of 1% molybdenite seems to be a little too high; 0·8% is probably nearer the actual content [11/1920, p. 464].

of molybdenum, and oil flotation is used in a mill of 200 tons capacity. The severity of the climate at this altitude renders work difficult for a large part of the year [122/p. 64].

About 11 miles S.W. of Breckenridge, Summit Co., at an altitude of 12,000 ft., molybdenite with some chalcopyrite is found in two pegmatite veins consisting of muscovite and quartz with some felspar, traversing a dark grey gneissose rock. A sample of 100 lb. of picked ore assayed 4·35% molybdenite with 0·45% copper [122/p. 67]. Other promising occurrences of molybdenite in Colorado are as follow: Gold Hill, 10 miles north of Pitkin; Tarryall Creek, 8 miles north of Lake George, Park Co.; Brown's Creek, Chaffee Co.; the Molybdenite Queen claim in the Iron Spring Mining district, near Ophir, San Miguel Co.; Chalk Mt., near Robinson, Summit Co.; from the northern slope of Rito Alto Peak in the Sangre de Cristo Range, Fremont Co.; a dump 12 miles north of Westcliffe, Custer Co.; and from the S.W. slope of Treasury Mt., 8 miles north of Marble, Gunnison Co. However, no detailed information is available as to any of these.

South Dakota

Molybdenite is recorded from the remarkable mineralized pegmatites of Etta Knob and Tinton (formerly called Nigger Hill) in the Black Hills, South Dakota, but it does not appear to exist in economic quantity.

Maine

Some years ago molybdenite was mined on a small scale at certain localities in the State of Maine. At Cooper, 22 miles S.W. of Calais, the American Molybdenum Co. worked some narrow veins of molybdenite-bearing pegmatite in a fine grey biotite-granite. Molybdenite was present in crusts and flakes in the middle of the veins and occasionally formed lumps up to 12 lb. in weight. The ore was particularly abundant in the more quartzose portions of the pegmatite. Fluorspar and a little native bismuth also occurred [131/p. 231] [114/p. 335]. Molybdenite was also disseminated throughout the granite mass [132].

At Catherine's Hill, Hancock Co., molybdenite is found in

flakes and bunches, sometimes as much as 5 in. across, in a series of pegmatite dykes composed of quartz, felspar and biotite; it is also found here and there disseminated in granite with a little pyrite [131/p. 235] [133/p. 42].

Molybdenite has also been found near Sand Cove, Tunk Pond, and in the town of Brunswick, Cumberland Co.—at both places in the granite [133/p. 47].

Montana

The molybdenite property of the Great Western Mining and Milling Co. is about 5 miles from Chico, Park Co., Montana, at an elevation of about 7,500 ft., in an outlying portion of the Absaroka Range. The deposit consists of a brecciated zone of grey porphyry permeated with pyrite and fine-grained molybdenite. Two samples were said to assay 14 and 23% molybdenite respectively, but these were probably specially selected. A test of several tons in a small experimental mill yielded 5 or 6%. In Carpenter Gulch, Powell Co., molybdenite occurs in fair quantity in a metamorphosed silicified limestone.

Nevada

At the Silver Pick mine, Goldfield, Nevada, molybdenite occurs at a depth of 1,320 ft. The content of molybdenite averages 2% [134].

New Mexico

The R. and S. molybdenum mine is 8 miles N.E. of Questa, Taos Co., New Mexico, at an altitude of 8,700 ft. The deposits consist of mineralized shear zones in a soda-potash alaskite-porphyry. The main fractures strike N. 79° W., or follow the main shear zones in the alaskite, but smaller veins and flats form a very complex network of branches, intersections and junctions. The vein-filling is made up mostly of quartz with a large proportion of molybdenite, some pyrite, a little chalcopyrite, and some fluorspar, sericite, apatite, biotite, chlorite and calcite. Molybdenite is found in bodies varying in size from the smallest films and flakes up to irregular lens-shaped masses 5 in. or more in thickness. The ore has probably been formed by ascending magmatic waters, probably at a moderate

temperature. The deposit has been worked to a depth of 300 ft. Molybdite occurs in the outcrop. The equipment of the mill consists of a jaw crusher, ball mill, classifier and flotation plant [135].

A small quantity of high-grade molybdenite concentrate has been obtained by the Romero Mining Co., working near Porvenir, San Miguel Co., from a pegmatite in which it is associated with chalcopyrite, scheelite bismuth minerals and fluorspar [125/1916, p. 778].

Texas

Molybdenite, in scales and masses up to 10 lb. in weight, is found in the great pegmatite intrusion of Baringer Hill, Llano Co., Texas, which is probably one of the richest deposits of compounds of rare elements in the world. The decomposition-product, powellite (calcium molybdate), is found in white crusts lining cavities formerly occupied by molybdenite [136].

Utah

At Alta in the State of Utah, at an altitude of 9,350 ft., the country rock is a siliceous limestone, near granite, intruded by dykes of rhyolite. The ore-bodies occur along a main fault, showing, in some places, 30 ft. of crushed limestone. Some of the fragments of the limestone are rounded, probably by the thermal waters. Wulfenite occurs in the crushed zones in small proportion, the principal metalliferous contents being argentiferous lead carbonates and oxides carrying small amounts of copper and gold. For many years silver-lead only was extracted from the ore, but recently the wulfenite has been separated as a molybdenum by-product. In the adjoining Old City Rocks mine, the silver-lead ore carries more copper and much more wulfenite than the Alta. The wulfenite occurs as delicate yellow scales in the decayed fragments of crushed limestone [131/p. 239].

Molybdenite has been mined from a deposit on the south side of Little Cottonwood Canyon, about 1½ miles below Alta. The ore is an impregnation in granite and is accompanied by pyrite and a little chalcopyrite [125/1916, p. 778]. At Gold Hill molybdenite is also found with chalcopyrite in a lime-silicate contact rock [137].

A remarkable and interesting deposit of a molybdenum compound of a deep blue colour and soluble in water was found in a Tertiary sandstone on the south side of the Duchesne River, 2 miles west of Ouray; this appears to be the rare mineral ilsemannite. The sandstone when mined is black, but dries to an indigo-blue colour. The bed varies in thickness from 8 in. to 3 ft. The extract from this rock can be used as a dye for various fabrics, especially silk, but the deposit is probably of no commercial value [125/1917, p. 913].

Washington

The earliest American workings for molybdenite, as already mentioned, were at a very remarkable locality at Crown Point, Chelan Co., Washington, near the summit of the Cascade Range at an elevation of over 5,000 ft. The ore-body is a large quartz vein outcropping for a length of several hundred feet on the face of a perpendicular cliff, 600 to 700 ft. high, in a narrow rocky gorge. The vein at its outcrop is nearly horizontal, having a dip of only 5° to the west, and the country rock is grey biotite-granite. The molybdenite occurs irregularly scattered through the white vitreous quartz or in seams several inches thick running across the vein, i.e. vertically. It occurs in the form of flakes and hexagonal pyramids up to 4 or 5 in. across [138] [122/p. 79].

Near Loomis, Okanagan Co., there is a "blow" or chimney of medium-grained light-grey granite in which molybdenite, associated with pyrite, occurs as small flakes up to ⅛ in. in diameter. The deposit appears to be 200 ft. by 400 ft. in dimensions, and probably averages 0·5% molybdenite. According to F. B. Lancy, the molybdenite is well distributed throughout all the specimens studied by him, but it appears to be more abundant in the more highly quartzose parts of the rock—hence the mineral is probably a late addition to the solidifying or partly solidified magma [122/p. 84].

SOUTH AMERICA

Argentina

Molybdenite has been found with tungsten minerals at San Virgilio in the Sierra de Córdoba, Argentina, but the quantity

available is not stated. The San Virgilio veins are apparently pegmatitic, lying partly in granite, with an average width of 20 in. and a dip of 50°. They contain wolfram, chalcopyrite, covellite, with abundant apatite and a little fluorspar in a gangue of quartz. At Los Coloraditos, in the Sierra de Velasco in La Rioja, is a group of quartz veins rich in wolfram and tourmaline, with lesser amounts of magnetite, pyrite, chalcopyrite, bismuthinite and molybdenite. The veins occur in the marginal facies of a muscovite-biotite-granite at its contact with gneiss, which is cut by numerous pegmatites with large tourmaline crystals [139/p. 62].

Bolivia

Some molybdenite occurs in the Tasna bismuth-silver-tin district, Department of Oruro, Bolivia, where a slate formation is cut by dykes of rhyolite.

In 1915 the exports of molybdenite concentrate from the Province of Larecaja, Department of La Paz, amounted to about six tons [11/1916, p. 514].

Chile

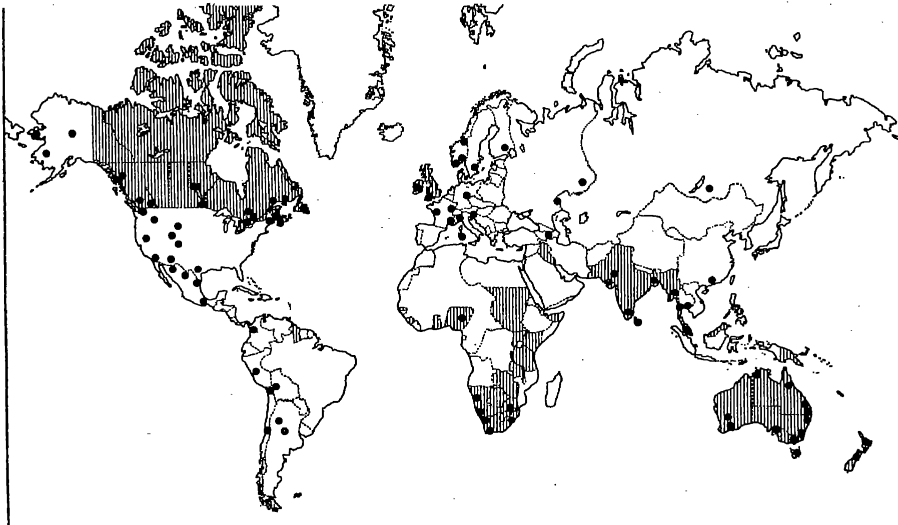
Molybdenite deposits were being worked in 1917 at Cupane, about 56 miles inland from the port of Arica, Chile. They are found at varied elevations in a region of very precipitous hills, where communications are difficult, and little is known of their geological relations [11/1917, p. 461].

Molybdenum ores are reported to occur at La Punta, 10 miles N.E. of the city of Santiago, and in some mines in the Department of Coquimbo [139/p. 282].

Peru

The molybdenum production of Peru comes from the Jauja province, Junín. The veins are found in the upper portion of granitic intrusions and near their margins. At Runatullo, in the Turma ridge, in the Ricrán region, the veins vary in width up to 15 in., and consist of quartz with flakes of molybdenite, with smaller quantities of chalcopyrite, pyrite, black and yellow blende, and muscovite. The country rock consists of sand-

stones and slates intruded by a white granitoid rock, the sediments having a N.E.–S.W. strike and dipping N.W. The Sociedad Explotadora de Molibdeno has undertaken here a certain amount of development. In the Torrioc ridge, on the hacienda Callan, and at Janchis-Jucha, veins with molybdenite are found striking N.N.W.–S.S.E., and dipping S.S.W. They lie in a crystalline eruptive rock, varying from granite to rhyolite, and consist mainly of quartz, with some pyrite and muscovite. The molybdenite lies mainly on the walls, but is also found scattered through the gangue; some of the veins are 50 ft. wide, but their content of molybdenite is not stated. At Tipillapa, to the S.E. of the foregoing locality, quartz with molybdenite has been found in loose blocks in moraines [140] [141]. Molybdenite also occurs in the district of Cascas, Province of Contumaza [11/1916, p. 514].



Map showing the Molybdenum-bearing Localities referred to in the Text.
(British Empire shaded.)

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